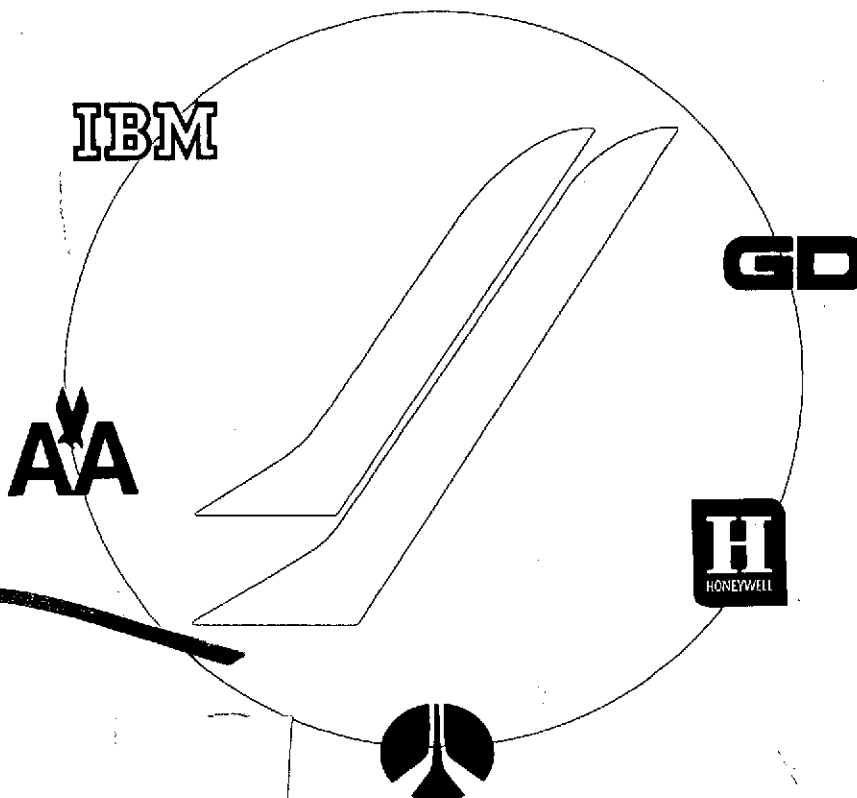


Space Shuttle Program

NASA/CR-134357

FINAL SUBMITTAL

MSC-03307



(NASA-CR-134357) SPACE SHUTTLE PHASE B.
VOLUME 1: EXECUTIVE SUMMARY Final
Report (North American Rockwell Corp.)
39 p

N74-75830

00/99 Unclass
47852

Phase B Final Report

Volume I. Executive Summary

Contract NAS9-10960
DRL M010, DRL Line Item 12
DRD MA016M
SD 71-114-1
25 June 1971

REPRODUCED BY
**NATIONAL TECHNICAL
INFORMATION SERVICE**
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

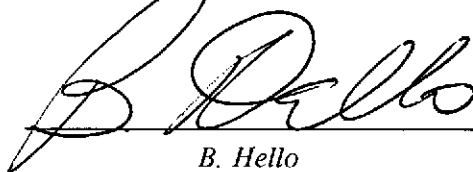
SD 71-114-1
(MSC 03307)

25 June 1971

**SPACE SHUTTLE
PHASE B FINAL REPORT**

**Volume I
Executive Summary**

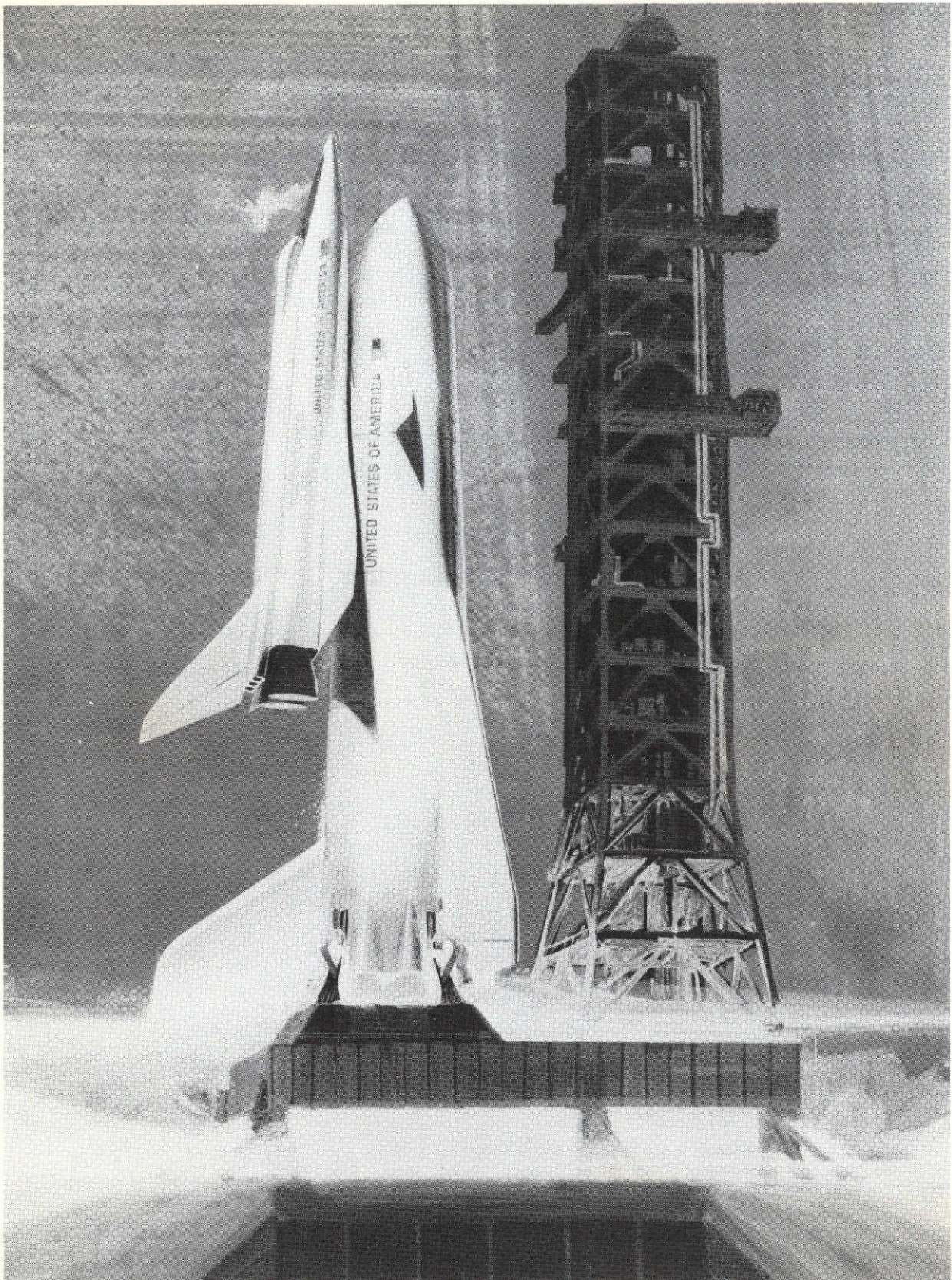
Approved by

A handwritten signature in dark ink, appearing to read 'B. Hello', is written over a horizontal line.

B. Hello

*Vice President and General Manager
Space Shuttle Program*

Contract NAS9-10960
DRL M010, DRL Item 12
DRD MA016M





INTRODUCTION

This document is a summary presentation of the Space Shuttle Program Definition Phase B Study accomplished by the North American Rockwell Corporation (NR) under Contract NAS9-10960 to the National Aeronautics and Space Administration Manned-Spacecraft Center, Houston, Texas. The basic study was conducted from July 1, 1970, through June 25, 1971, by the NR Space Division and a team of four major subcontractors: the Convair Aerospace Division of General Dynamics Corporation, San Diego, California; American Airlines, Tulsa, Oklahoma; Space Systems Center of International Business Machines, Huntsville, Alabama; and the Aerospace Division of Honeywell, Incorporated, Minneapolis, Minnesota. International cooperation and assistance in the Phase B study effort was obtained from two European companies: The British Aircraft Company and Messerschmitt-Boelkow-Blohm, who were sponsored by their respective governments. Other contributors to the study are identified on the following page.

Study Reports

The entire study final report is presented in three volumes: this document, Volume I, *Executive Summary*; Volume II, *Technical Summary*, Books 1 through 4; and Volume III, *Program Acquisition Plan Summary*. A list of documentation related to the Final Report is given on Page 36.

Final reports for three major add-on studies to Contract NAS9-10960 are presented under separate cover. They are NR Report SD 71-140, *Expendable Second Stage Phase A/B Study*; SD 71-141, *Orbiter External Hydrogen Tanks*; and SD 71-142, *DOD Mission Impact Study*. A fourth major add-on effort is the Phase B Structural Test Program, which is currently in progress toward planned completion in March, 1972.

Study Objectives

In pursuit of the overall goal of the Space Shuttle Program to provide an economical space transportation system, North American Rockwell directed its studies toward achievement of several essential system characteristics: an operational mode that will reduce present costs by

an order of magnitude, a flexible capability to support a variety of payloads and missions, an airline-type operation for passenger and cargo transportation, and a reusable system with high launch rate capability and short turnaround and reaction time compatible with rescue missions.

Four fundamental objectives were set forth by NASA at the outset of the Phase B program to guide all study activities. They were

1. To define the space shuttle system.
2. To accomplish preliminary design of the space shuttle with its orbiter optimized for two levels of crossrange capability, 200 and 1500 nautical miles.
3. To obtain an understanding of the scope, schedule, and cost of the space shuttle system.
4. To obtain an understanding of the supporting research and technological advancement required.

In the course of the study, NASA modified these original objectives as necessary to accommodate new study findings and changes in mission requirements. Continuous observance of the basic objectives and incorporation of updated concepts by the NR study team has resulted in the definition of a system that reflects the optimum approaches available throughout the entire study period.

Conclusions

Conclusions to be drawn from the Phase B study are affirmative in all respects. A cost-effective, multipurpose, reusable space-transportation system can be delivered in time to support routine operations throughout the 1980's. Existing production, test, and operations complexes; skilled manpower reserves; and accumulated technology require comparatively little augmentation to accommodate the space shuttle program. Areas involving technological advancement are shown to be few and devoid of insurmountable problems. At this time, technically feasible designs, realistic program plans, and reliable cost estimates are available to support the earliest possible go-ahead into the space shuttle production and operation phases.



Phase B Subcontractors

Technical and costing assistance was received from numerous companies during

Space Shuttle Team Members

General Dynamics Corp., Convair Aerospace Division
International Business Machines Corp., Space Systems Center
Honeywell, Inc., Aerospace Division
American Airlines

Other Funded Subcontractors

General Electric Company, Re-Entry and Environmental Systems Division
Beach Aircraft Corp., Boulder Division
Chrysler Corp., Space Division
Holmes and Narver
LTV Corp., Vought Missiles and Space Co.

Unfunded Subcontractors

Aerojet General Corporation Liquid Rocket Division
Allis Chalmers, Advanced Electro-Chemical Products Division
Bell Aerosystems Company
Cleveland Pneumatic Tool Company
Collins Radio Company
Dalmo Victor
The Garrett Corp., AiResearch Manufacturing Division
General Electric Company, Defense Programs Division
Goodyear Aerospace
Hamilton Standard

Honeywell, Inc., Aerospace and Defense Group
Hughes Aircraft Co., Communications and Radar Division
Ling Temco-Vought, Inc., Vought Aeronautics Division
LTV Corp., Vought Missiles and Space Co.
Motorola, Inc., Government Electronic Division
Pratt & Whitney

Radiation, Inc.
Radio Corporation of America, Defense Electronics Products
Rohr Corp.
TRW Systems Group
Westinghouse Electric Corp., Aerospace Electrical Division
Westinghouse Electric Corp., Space Communications Division

International Participants

British Aircraft Company, Ltd.
Messerschmitt-Boelkow-Blohm

Phase B through both funded and unfunded subcontracts. The following is a list of contributing firms and the areas of technical and/or cost-estimating assistance.

Booster vehicle
Data control and management; displays and controls
Guidance, navigation, and control
Maintenance and operations

Reusable external insulation

Cryogenic tankage
Vehicle production
Facilities
Rigidized pyrolyzed plastic

Auxiliary propulsion, pump package
Fuel cells
Auxiliary propulsion, pump package
Landing gear
Communications
Antennas
Auxiliary power unit; environmental control
Air-breathing engines; fuel cells
Crew transfer structure
Environmental control; waste management; life support; auxiliary power system
Propellant management and gauging
Antennas
Antennas
Radiator panels
Communications
Fuel cells; main engine; air-breathing engines; auxiliary propulsion pump package
Television applications
Orbiter/booster data link
Air-breathing engine nacelles and pylons
Auxiliary propulsion; pump package
Inverter; electrical power distribution and control
Orbiter/booster data link

Vertical stabilizer, cargo bay doors, test flight instrumentation
Auxiliary propulsion



STUDY BACKGROUND

The Space Shuttle Program, which has progressively taken form throughout the past decade, now stands defined in all its major aspects. A basic concept has been established; and all significant design, manufacturing, operational, and funding considerations have been identified. Following NASA evaluation of the recently completed Phase B Definition Study, a program to design, fabricate, test, and operate the actual shuttle system can be initiated.

The economic necessity for a reusable space shuttle system has been recognized for many years; however, this need has increased markedly with currently mounting requests from the scientific, military, and commercial communities to obtain the benefits available from earth-orbiting laboratories and instrumentation.

Beginning in the early 1960's, the Government sponsored numerous studies to explore the feasibility of reusable vehicles to transport men and a variety of equipment between earth bases and selected space orbits. Ideally, the transport vehicles envisioned would resemble commercial aircraft in both design and operation and would eliminate the expenditure of a costly launch vehicle with each payload delivery.

These preliminary investigations culminated in 1969 with initiation of concept feasibility (Phase A) studies. Under these contracts, concepts were evaluated and requirements were accumulated for the NASA integral launch and reentry vehicle (ILRV) and for the Air Force space transportation system (STS).

A number of important conclusions resulted from the Phase A efforts. Study of the lifting-body, or wingless class of vehicle indicated that it was not compatible with efficient cargo packaging, subsystem arrangement, or conventional fabrication practices and that it did not exhibit the needed subsonic lift-to-drag ratio. Examination of the winged, two-stage, reusable vehicle, meanwhile, revealed that this concept was adaptable to many

of the projected mission requirements, but that further design studies and development testing would be required to establish optimum aerodynamic configurations and trajectories for both the booster and orbiter stages. Mission abort considerations, furthermore, had been minimal, and wind tunnel testing had been limited to low Mach numbers.

A key factor in achieving low-cost operation was found to be the development of a reusable heat-shield system. Such a thermal protection system, which involves some degree of technological advancement, has significant impact upon structures; weights; manufacturing; maintenance; and, depending upon its effectiveness, the reentry profile and crossrange capability.

Determination of the optimum crossrange, or lateral maneuver capability during reentry, was recognized as a second critical issue because of its impact on vehicle design and cost. The straight-wing orbiter studied during Phase A was found to be capable of a maximum crossrange of about 1240 nautical miles, but at a low reentry angle of attack with severe heating problems. (A subsequent study showed that a crossrange of 1500 nautical miles could be achieved under more desirable entry conditions with a delta-wing orbiter of otherwise similar dimensions.)

At the conclusion of the Phase A studies, the crossrange considerations were reported along with feasibility data concerning all major aspects of the existing concepts. In addition, preliminary schedules for development, manufacture, and operation of the space shuttle system were prepared; and program costs were estimated on the basis of the limited definitive information then available. Subsequent review and evaluation of the Phase A findings were accomplished by NASA; and in February, 1970, a statement of work detailing requirements of the Phase B Space Shuttle Definition Study was issued with a request for proposal.



THE PHASE B STUDY PROGRAM

In July, 1970, the North American Rockwell Space Division was awarded a twelve-month Phase B study contract to define the space shuttle system in detail and to establish a high level of confidence in the proposed technical design, program approach, mission requirements, and cost estimating procedures.

Activities of the Phase B study were aligned by NR to obtain the maximum benefits of its highly specialized aerospace disciplines in engineering, manufacturing, and management. Resulting general study requirements were presented as follows:

- A requirements review to consolidate and evaluate study ground rules and constraints and to verify the desirability of proposed system characteristics.

- Definition of configurations, subsystems, operations, facilities, and ground support equipment.

- Preliminary design down to the assembly level, development of specifications, and identification of all booster-orbiter interfaces to permit separate booster and orbiter contracts if desired.

- A test program, supplemented with applicable data from Government and industrial sources, to substantiate vehicle design features and weight estimates as affected by aerodynamics, structures, stability and control, aerodynamic heating, and thermal protection systems.

- Resource and cost analysis to obtain reliable estimates of total program costs as well as recurring operational costs.

- Continuation of on-going weight-performance and cost-schedule studies.

- Exchange of information, under NASA coordination, with separate space shuttle technology and main engine design programs.

- Documentation of Phase B study results and Phase C/D program plans.

Several areas of critical interest existing at the beginning of the Phase B study received special emphasis in the delineation of objectives. It was directed that essential research and technological advancement be identified and evaluated for impact upon the total program. The element of particular concern in this regard was development of suitable reusable thermal protection for the booster and orbiter vehicles. Several

protection systems had been suggested; however, it was realized that each involved the use of materials and methods requiring advancement of current technology.

Also remaining unresolved at the beginning of Phase B was the major system capability of aerodynamic crossrange. Although the booster was expected to remain essentially unaffected by long or short orbiter crossrange, distinctly different orbiter configurations were envisioned with attendant variations in cost. To promote this basic decision, it was requested that preliminary design studies be initiated to optimize an orbiter with 200-nautical-mile crossrange capability and an alternative version with 1500-nautical-mile crossrange capability. Complete booster and orbiter redesign was permitted if necessary to achieve full compatibility with each crossrange.

In view of the magnitude of this dual design effort, NASA indicated that all work would be redirected toward a single configuration should a crossrange decision be made at any time prior to completion of the Phase B study. (Such a decision was communicated to NR in January, 1971; and design was immediately concentrated on a delta-wing vehicle with an 1100-nautical-mile crossrange capability.)

Supplementing the investigations outlined in the basic Phase B contract was a structural concept evaluation and demonstration program. This effort entailed the fabrication and testing of large or full-scale sections of primary structure, thermal insulation, tankage, and elements involving composite construction or unique fabrication techniques. The intent of this program was to verify weight estimates and thermal protection efficiency as well as producibility under advanced manufacturing concepts.

The initial scope of Phase B was further expanded with three additional studies: to determine the impact of DOD mission requirements on the space shuttle defined in Phase B, to perform concept selection and definition of an expendable second stage for use with the shuttle booster to launch extremely large payloads, and to investigate the relative merits of an alternative space shuttle concept in which the orbiter is equipped with external hydrogen tanks. Results of these studies appear in separate final reports.

To promote orderly accomplishment of the broad range of Phase B study



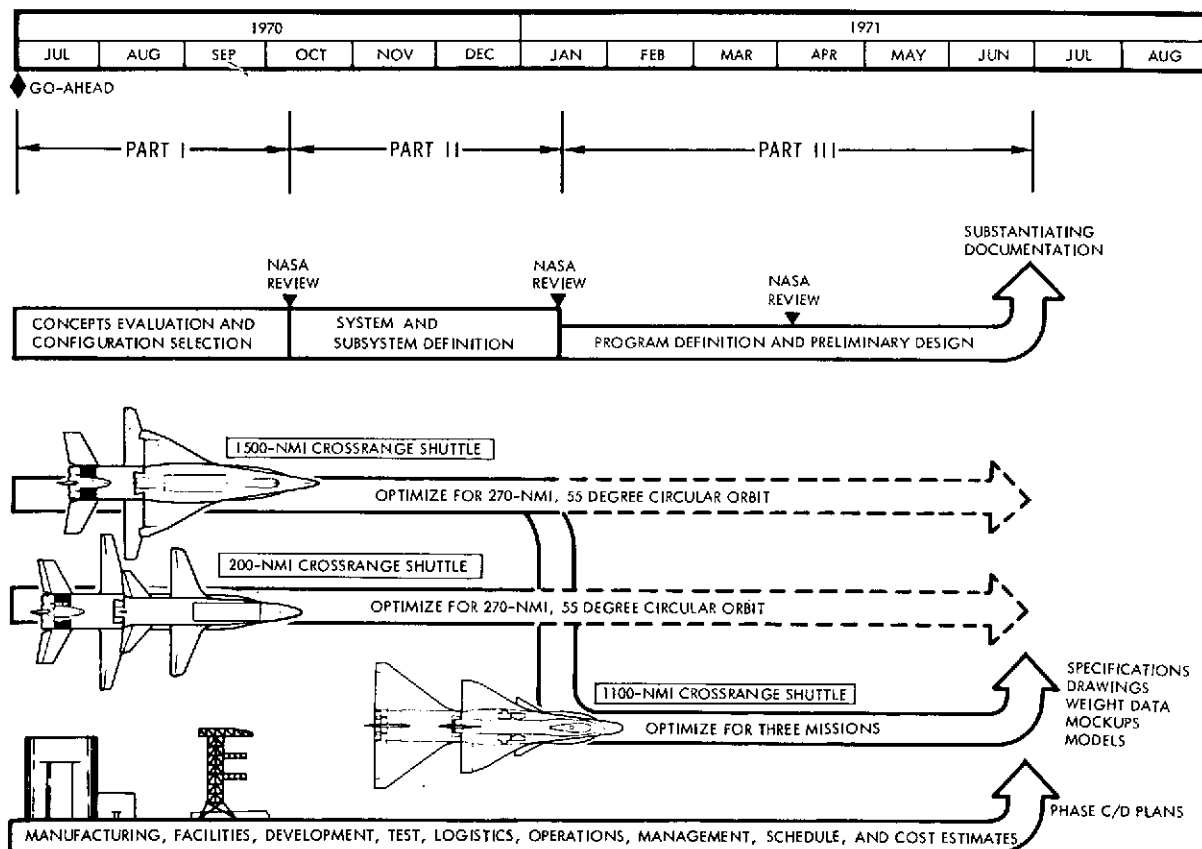
objectives, North American Rockwell segregated the required tasks into three categories, or study parts. Arranged to be performed sequentially, Part I included concept evaluation and configuration selections; Part II, system and subsystem definition; and Part III, program definition and preliminary design, each punctuated with appropriate formal review by NASA.

At the beginning of the study, concurrence was obtained with NASA on a detailed Phase B study plan, major study milestones, initial program and system baselines, and trade study ground rules. Early arrangements were also made for information exchange with other NASA and DOD studies having related objectives: Shuttle Engine, Space Station, Orbit-to-Orbit Shuttle, Alternate Space Shuttle Concepts, Orbital Propellant Facility, and Space Tug.

During Part I, of approximately three months duration, the 200- and 1500-nautical-mile crossrange shuttle systems were used as initial baseline configurations for analyses and trade studies. Results of these efforts, in addition to

resolving most basic issues, led to revision of many of the preliminary mission, vehicle, and operations requirements established earlier. Two refined configurations were identified; the critical thermal protection concepts were selected for evaluation; and work was begun on the study of an expendable second stage.

Part II, also conducted for approximately three months, was directed toward selection of optimum vehicle systems for use in Phase B preliminary designs. In support of this objective, studies were performed to obtain additional critical data on the boost and entry environment, vehicle operations, and costs. Costing was performed to the assembly level and, in certain critical areas, such as the thermal protection system, to the component level. Further substantiation for subsystem selection was gained by in-depth investigation of program planning and major resource requirements for their effects upon fabrication, handling, quality control, and testing of hardware. The trade studies and selections were supported by generation of preliminary design



Phase B Study Flow



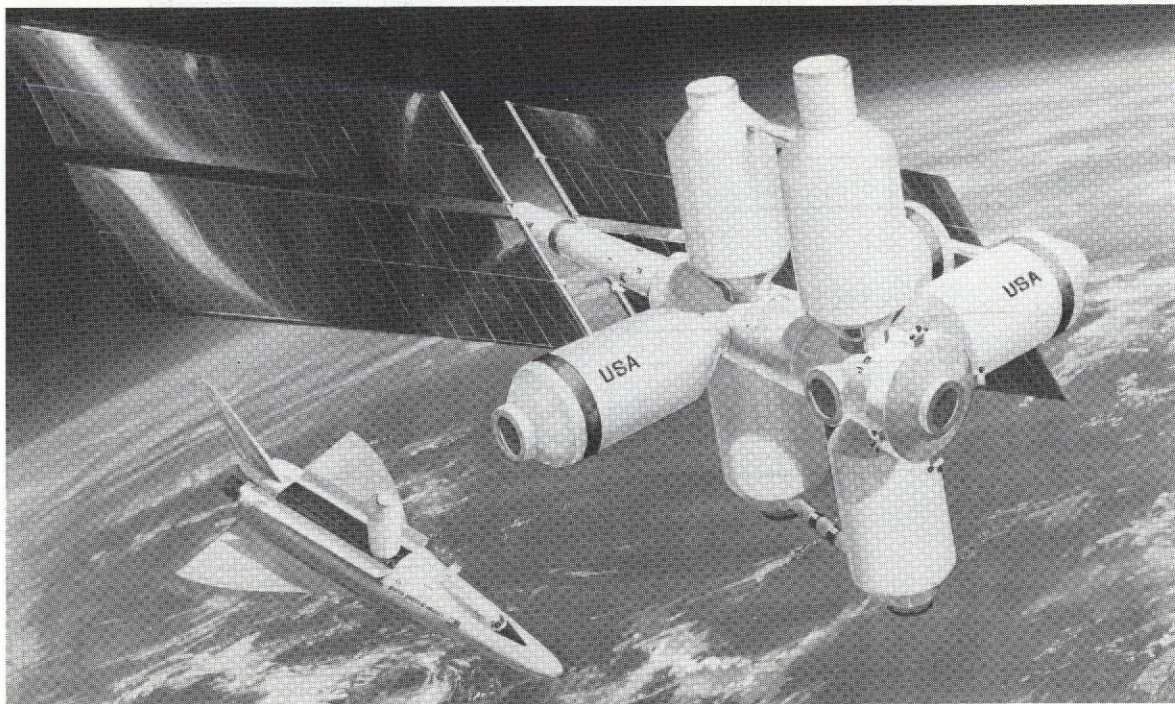
data, configuration drawings, mass property calculations, and performance estimates. Work on the structural test program and a DOD mission impact study was commenced during Part II.

Part III, consisting of program definition and preliminary design, was performed throughout the last six months of the study. It was begun with NASA redirection to devote all further effort to a single system optimized for three specific missions, and having the aerodynamic crossrange capability to return to the launch site at the end of one orbit. In response to this instruction, NR resized the high-crossrange delta-wing orbiter to meet the new program requirements. Preliminary system designs were completed for flight hardware, and ground equipment requirements were identified. Vehicle components were integrated to produce the most efficient external aerodynamic shape and internal equipment arrangement, and wind tunnel testing was performed to verify aerodynamic characteristics. Parallel work was also performed on the study to evaluate the use of external hydrogen tanks. Final documentation of the Phase B definition study comprised program plans, drawings, end-item specifications, interface control documents, and a systems definition handbook. Soft mockups of the orbiter and booster crew compartments also were produced.

Throughout the Phase B study, the North American Rockwell Space Division retained prime responsibility for program integration, system integration, and orbiter vehicle definition. Definition of the space shuttle booster vehicle and related ground operation was performed by the Convair Aerospace Division of General Dynamics Corporation, which served as a team member with NR. Other team members providing major technical contributions were American Airlines (maintenance and ground handling), Honeywell (avionics systems), and IBM (electronic data management systems).

Responding to the stated national desire for international space cooperation, the Space Division entered into agreements with two European companies through their governments to provide technical assistance in specific nonclassified and nonproprietary areas. The British Aircraft Company assisted in preliminary design of certain orbiter structures and flight test instrumentation systems, while Messerschmitt-Boelkow-Blohm of West Germany provided preliminary design of the attitude control propulsion systems.

The remainder of this document is a concise review of study results, conclusions, and projections presented by major system and program element. All information provided herein is substantiated in detail in the various Phase B final report documents.



Space Station Logistics Mission



OPERATIONAL CONCEPT

The following summary of Space Shuttle operations is based on performance data, design concepts, and mission requirements existing at the conclusion of the Phase B Definition Study. Understandably, certain aspects of the concept described herein may be modified in response to unforeseen technological breakthroughs, fluctuation of national and international conditions, and new mission requirements. The presently defined system, nevertheless, can accommodate considerable variation within the limiting criteria now established.

Major elements of the system are the booster vehicle, the orbiter vehicle, and the launch operations and service complex. Acquisition of these three entities, while dependent on the accomplishment of new research and development in several areas, is based on maximum exploitation of the enormous nationwide reserve of advanced technology, skilled manpower, and existing facilities.

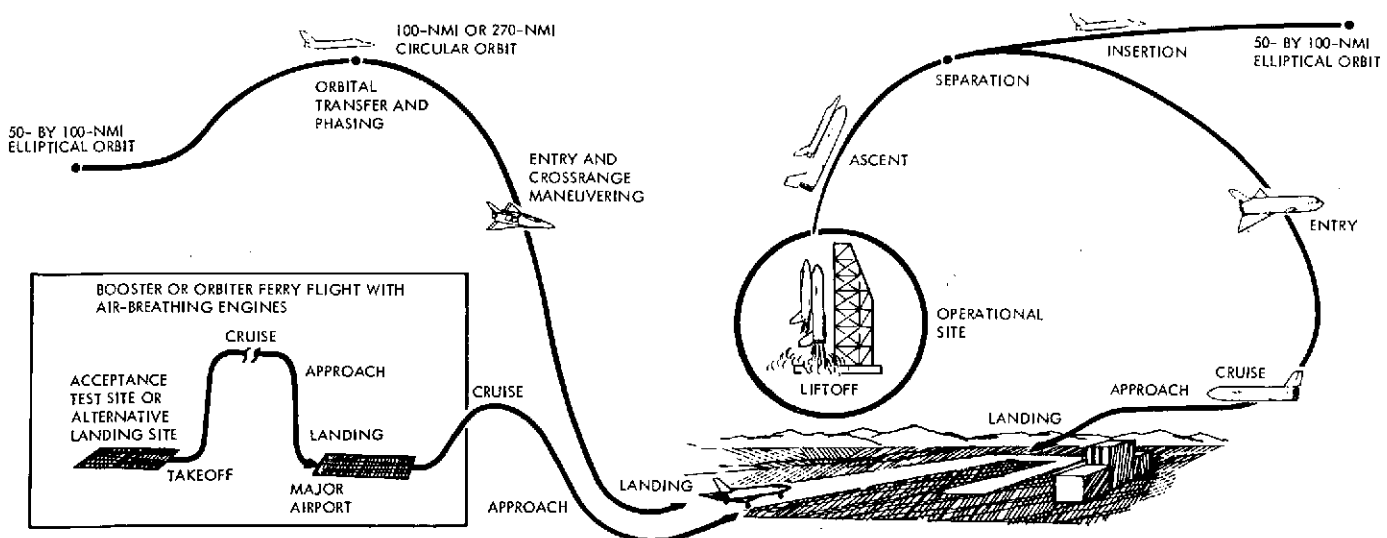
Preparations for space shuttle launch normally require approximately four days. The launch sequence begins with independent premate checkout of the separated booster and orbiter vehicles in the assembly building. Payloads, which themselves may consist of complex systems requiring fueling and monitoring, are installed in the orbiter cargo bay. The two vehicles are then erected to the vertical position; the booster is

mounted on the launch umbilical tower; the orbiter is attached to the booster; and the mated vehicles are transported from the assembly building to the launch pad.

Following arrival at the pad, launch-readiness checkout is performed; and the five-hour launch countdown is commenced with loading of propellants. When loading is completed, the crews and passengers board the vehicles for terminal countdown and launch.

The booster's twelve main engines are fired; and within three minutes after liftoff, the combined vehicles achieve a comparatively level course at an altitude of 200,000 feet. In rapid succession, the orbiter's two rocket engines are ignited, the booster engines are shut down, and separation of the two vehicles occurs. As the orbiter accelerates toward orbit, the booster prepares for return to the launch site.

Assuming an entry attitude and descent trajectory that produce minimum aerodynamic heating, the booster descends unpowered for the next seven minutes to an altitude of approximately 20,000 feet. Twelve air-breathing turbofan engines are then deployed beneath the wing and started. At approximately 15,000 feet, the booster assumes a typical aircraft cruise mode under which it flies back to the launch facility and lands on a conventional runway.



Basic Shuttle Operational Sequence



The orbiter, meanwhile, continues to accelerate until an elliptical insertion orbit of 50 by 100 nautical miles is achieved. The two main engines are then shut down, and the three smaller orbit maneuvering engines are ignited to place the vehicle in the desired circular orbit. Depending on the mission, this orbit may be established at a nominal 100 to 500 nautical miles for earth surveys or for placement, servicing, and retrieval of instrumented satellites, or it may be established at 270 nautical miles for delivery and pickup of supplies, equipment, and personnel for the manned orbiting space station.

Final critical adjustment of the orbiter into its working position is accomplished with the attitude control propulsion system consisting of 29 small thrusters located at various points on the vehicle. Once the vehicle is stabilized, the cargo bay doors are opened and payload modules are loaded or unloaded.

Cargo handling is accomplished by means of a pair of articulated manipulator arms. Movement and positioning are precisely controlled by cargo specialists located in the cargo-handling station aboard the orbiter. Television monitors and floodlights strategically mounted on the arms ensure visibility during these operations. Transfer of personnel between the space station and orbiter is performed directly through an airlock and docking port.

The orbiter is normally stocked with sufficient consumables to remain on orbit for up to seven days, although longer stay-times can be achieved with additional supplies. Such orbiter capability provides standby transportation for earth-based specialists who may be required to perform temporary services aboard the space station or on orbiting instrument packages. It also affords the opportunity for many types of short-duration studies to be performed directly from the orbiter.

On completion of the orbital operations, the orbiter is maneuvered to a 100-nautical-mile orbit and rotated to a deorbit

attitude. The orbit maneuvering engines are then fired to decelerate the vehicle and initiate descent. During reentry, the vehicle attitude is controlled to achieve any lateral crossranging required to assure the closest glide approach to the landing site. At 35,000 feet, four air-breathing turbofan engines are deployed from the dorsal surface and started to provide maneuvering capability to the launch site. When greater payload capability is required, these engines are removed and the orbiter accomplishes an unpowered return to the launch site. Landing is made with typical aircraft-type landing gear and a drag chute.

Both the orbiter and booster are capable of horizontal takeoff and flight powered by their air-breathing engine systems only. This capability enables the vehicles to return to the launch site following landings at alternative sites if required.

Ground turnaround procedures are essentially the same for booster and orbiter. Under normal conditions, the elapsed time between landing and launch readiness is fourteen calendar days. After landing, the vehicle is immediately taxied or towed to a safing area, where the crew and passengers deplane, mission flight data are removed, fluids and cold gas residuals are drained or vented, and the propellant tanks are purged with nitrogen. The safed vehicle is then towed into a maintenance hangar; service stands are installed; and cargo is removed (from the orbiter). If desired, a postflight checkout may be performed; otherwise, preventive and corrective maintenance, as well as repair, servicing, and modification, are commenced promptly. These functions constitute the most extended effort of the two-week turnaround cycle and are performed with a large assortment of support equipment items. During this period, maximum use is made of the computer-controlled on-board self-checkout and fault-isolation features of both orbiter and booster. On completion of postmaintenance checkout, the processed vehicle is towed to storage or placed on flight status.



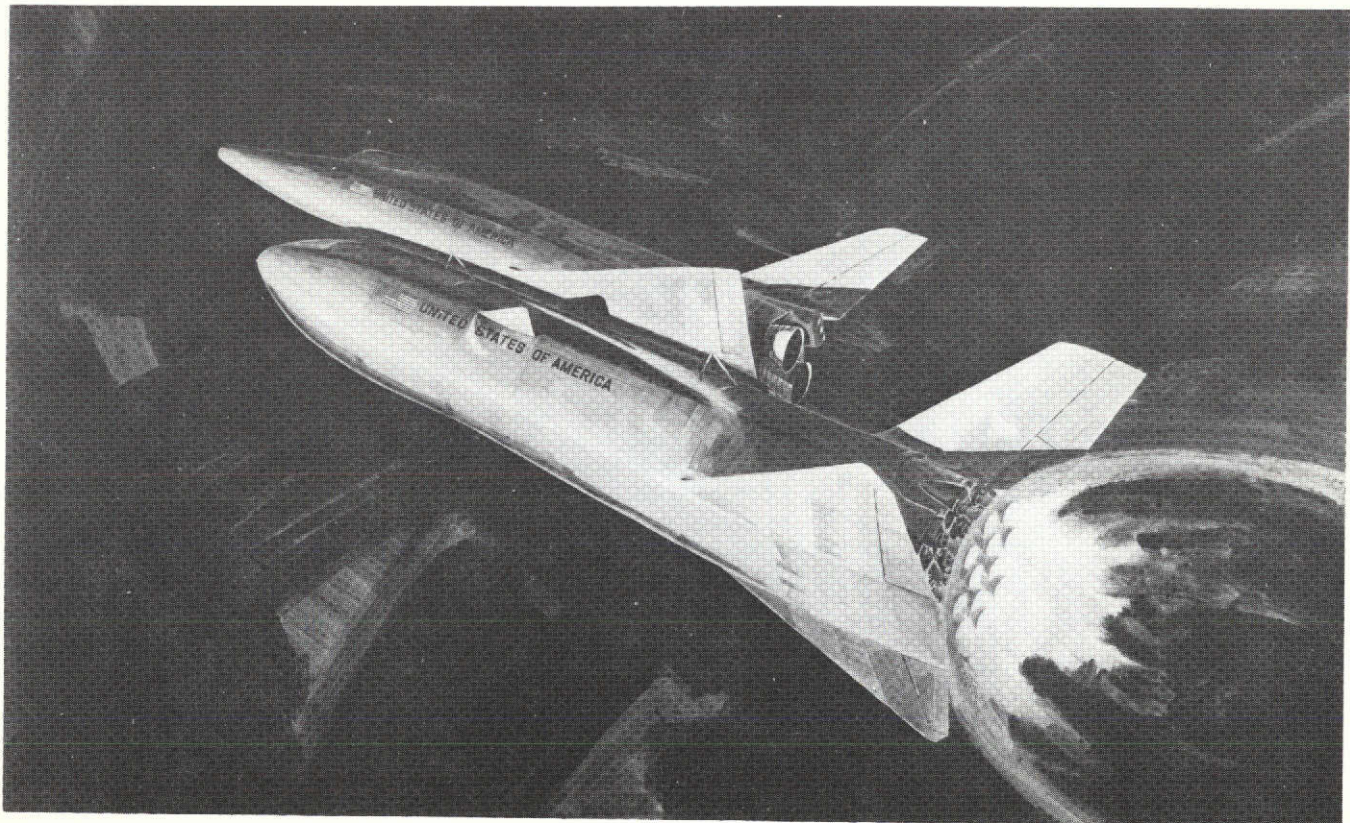
SHUTTLE SYSTEM DEFINITION

As a logical prelude to definition of the space shuttle system, the initial Phase B activity included analysis of the missions then planned. The most imposing mission demands were identified and established as target criteria for vehicle capability assessment.

Among these early requirements was the fundamental shuttle objective to transport a variety of payloads to and from a manned space station orbiting at 270 nautical miles. Maximum attainable payload capability was desired within the constraints of a 3.5-million-pound vehicle gross liftoff weight and a main propulsion system thrust not exceeding 415,000 pounds per engine. The payloads were to consist of personnel, supplies, equipment, and waste materials, each involving specialized containment and preservation systems. Inherent in these requirements was an index to all necessary shuttle vehicle performance characteris-

tics. Similarly, the shuttle system ground operations requirements were implicit in the request for extremely rapid turnaround capability; flight preparation, launch, docking, and transfer of personnel from the space station were to be accomplished within forty-eight hours of an emergency rescue call.

Comprehensive engineering studies were initiated to define cost-effective vehicle configurations exhibiting optimum performance up to, and including, these mission extremes. Although primary emphasis was placed on analysis of the straight-wing orbiter system with its 200-nautical-mile crossrange, in-depth study of the 1500-nautical-mile-crossrange delta-wing version was pursued. Early studies of projected missions that could be accomplished by the space shuttle indicated that the extended crossrange capability would offer greater mission flexibility.



Shuttle Ascent



In addition to concentrated system conceptual efforts in the broad fields of mission analysis and operations analysis, critical design studies were carried out in the specialized areas of structures, materials, aerodynamics, mass properties, propulsion, avionics, and ground support systems. Major supporting investigations were performed by groups of specialists assigned to space shuttle facilities and site selection, manufacturability, reliability, safety, program management, and cost analysis. Efficient integration of these efforts was assured by extensive use of the trade-study approach whereby system options, recommendations, and selections developed within the specialized groups are examined and approved by management review boards.

Preliminary synthesis of the two candidate concepts was accomplished during the first several weeks of the study by application of a vehicle design computer program. Preliminary weight-scaling relationships among the major structural elements as well as the weight allocations for subsystems were used in the initial assessment of vehicle and system capability. Results of these first vehicle syntheses, together with results of detailed shuttle applications studies, indicated that the imposed gross weight and thrust

limitations reduced shuttle payload capability to an undesirable level. NASA responded with directives to remove the 3.5-million-pound gross weight limitation and to design for launching a 25,000-pound payload into a 55-degree, 270-nautical-mile orbit. The redefined system exhibited the required payload capability, however, at the expense of more booster engines to accommodate the increase in gross liftoff weight.

Resynthesis continued throughout the first half of the study and accommodated a variety of updated requirements. The 415,000-pound main-engine thrust restriction was removed to arrest the trend toward an excessive number of booster engines; conventional JP fuel, instead of hydrogen, was selected for the air-breathing engine system; and application of a ten-percent weight contingency was specified for all designs. The shuttle vehicle configurations defined at the end of the first six months incorporated all of the changes developed and had a combined liftoff gross weight just below 5 million pounds and main rocket engines with a recommended sea-level thrust of 540,000 pounds each.

Findings of the early shuttle applications, or traffic, study were particularly interesting in that the preponderance of planned shuttle



Shuttle Orbiter



missions was found to have shifted from space station resupply to emplacement, servicing, and retrieval of satellites in 100-nautical-mile orbit. Shortly after the ninety-day study review, the change in mission emphasis was confirmed by NASA with issuance of a combined NASA and DOD traffic model, which showed less than 20 percent of the missions to be for space station resupply and more than 75 percent for satellite deployment and maintenance in the lower orbit. Increased payload capability became especially desirable in view of certain missions newly identified by NASA in the traffic model. Payloads as great as 73,500 pounds were indicated.

By the beginning of the third study quarter (January, 1971), results of the continuing analyses enabled NASA to fix main engine sea-level thrust at 550,000 pounds each, identify three basic shuttle missions, select an 1100-nautical-mile crossrange capability, and restrict all further study to the high-crossrange orbiter and booster configuration.

The three missions specified were (1) a due-east launch to a 100-nautical-mile orbit, (2) the previously defined 270-nautical-mile-orbit space station resupply mission, and (3) a south-polar launch to a 100-nautical-mile orbit. Payload for the space station mission remained at 25,000 pounds; however, the payload for the polar launch was established at 40,000 pounds and, for the due-east mission, at 65,000 pounds.

General configurations and characteristics of the space shuttle vehicles defined at the conclusion of the Phase B program have remained similar to those envisioned at the outset of the study. Details of system design and critical capabilities, however, are vastly refined and reflect the intense effort put forth by both NASA and the NR team to establish confidence in all aspects of the space shuttle system.

The Orbiter Vehicle

The orbiter configuration ultimately defined by the Phase B study is a delta-wing vehicle with an overall length of 206 feet and a wingspan of 107 feet. The outboard profile of the orbiter, closely resembling that of a conventional delta-wing aircraft, incorporates an unusually wide center fuselage (45.5 feet), which houses the two main liquid-oxygen tanks and a cargo bay 15 feet wide and 60 feet long. Forward volume of the fuselage is occupied by the main liquid-hydrogen tank and the crew compartment. Protection of internal structures is achieved with reusable heat

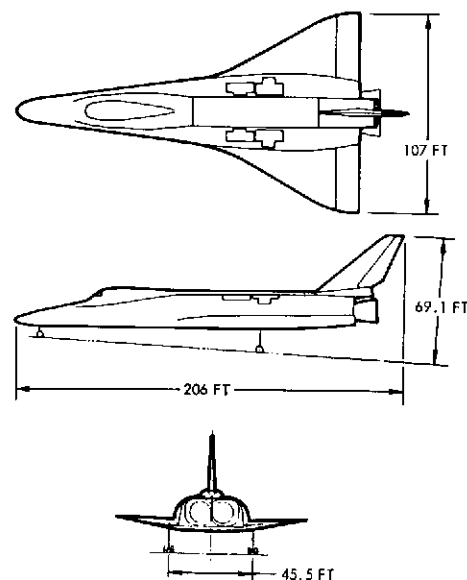
shielding over all external surfaces subjected to the high heats of boost and reentry.

Extensive use of computerized control and data management permits full orbiter flight operation with a crew of two, commander and pilot. Two additional personnel are carried as cargo specialists when payloads are to be deployed, maintained, or taken aboard while in orbit.

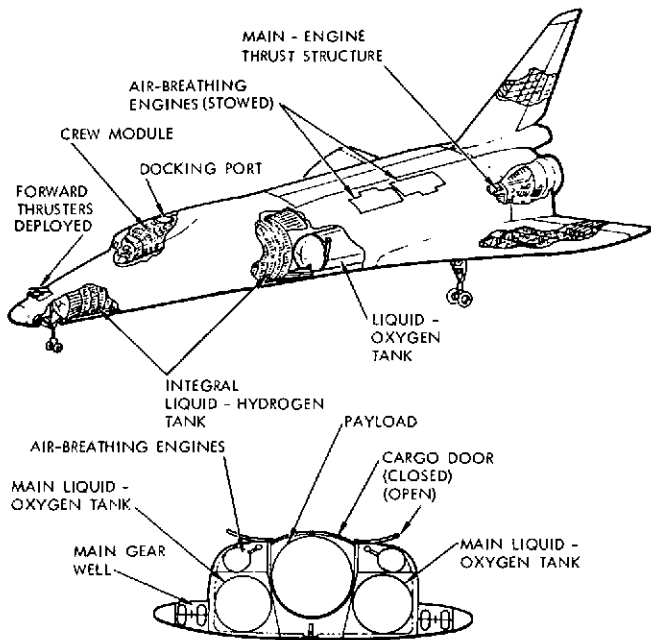
Aerodynamic flight control is achieved with typical rudder and elevons, while exoatmospheric attitude control is sustained with a system of jet thrusters.

The main propulsion system consists of a pair of rear-mounted liquid-propellant rocket engines, which, with nozzle extensions, develop a vacuum thrust of 632,000 pounds each. The main engines are used to propel the orbiter from booster separation to initial orbit only. Subsequent orbital transfers and deorbiting are accomplished with three smaller orbital maneuvering engines mounted above the main engines. Following reentry, four air-breathing turbofan engines are deployed above the center fuselage to provide go-around and landing maneuver capability. The air-breathing engine system, when augmented with a fifth engine mounted beneath the fuselage, delivers sufficient thrust for horizontal takeoff and ferry flight when required.

General arrangement of the orbiter is dictated by a number of basic design and operational objectives: achievement of airline-type vehicle design and operational characteristics, controlled atmospheric and exoatmospheric flight,



Orbiter Configuration

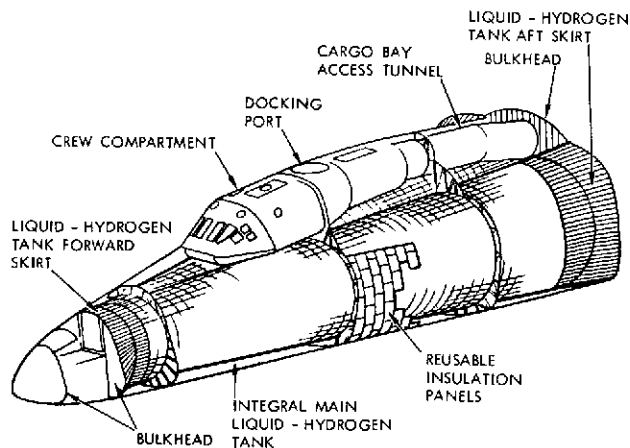


Orbiter General Arrangement

extended crossrange capability, high payload capacity, and accommodation of large amounts of cryogenic propellant.

The orbiter fuselage is fabricated in three major assemblies: the forward body containing the main liquid-hydrogen tankage and crew compartment; the center body containing the main liquid-oxygen tankage, turbofan engines, and cargo bay; and the aft body containing the main rocket engines, orbit maneuvering engines, and attach points for the vertical stabilizer and wings.

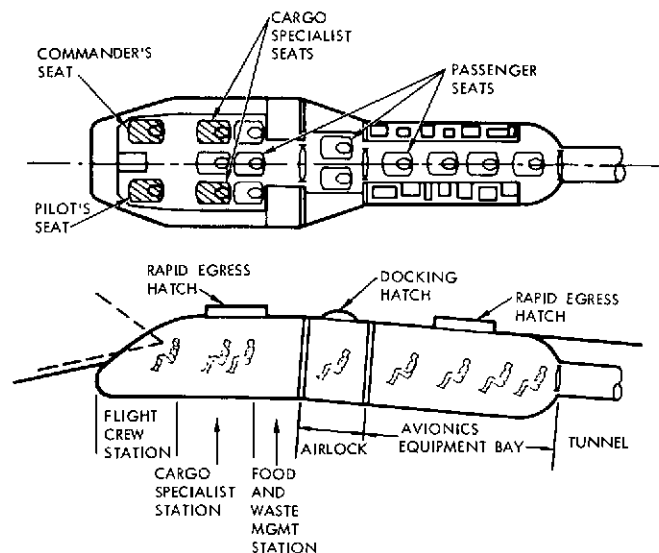
The essential volume of the forward fuselage consists of the large conical main liquid hydrogen tank. Designed as an integral structure,



Orbiter Forward Body

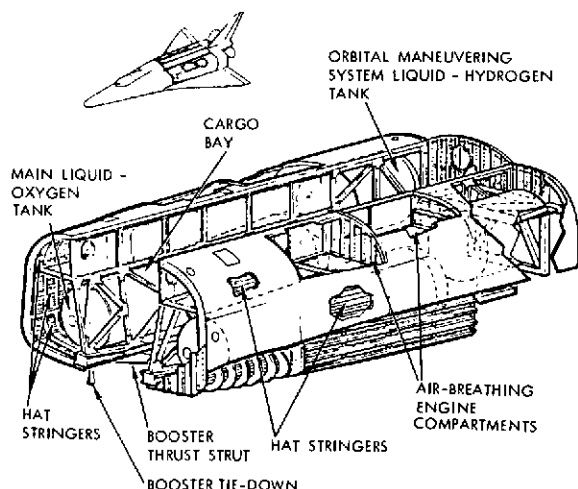
the tank is fabricated as a complete fuselage section, including the external thermal protection system support structure. Supported on the forward end of the tank structure is the nose compartment, which houses the retracted nose landing gear and portions of the avionics system.

The fully instrumented, environmentally controlled crew and passenger module is a compartmentalized cylindrical structure mounted atop the main hydrogen tank in the forward fuselage assembly. In the forward section are the commander's and pilot's stations with vehicle controls and displays. Also located in this compartment are accommodations for two cargo specialists, four of the ten passengers, general life support equipment, and personal stowage provisions. Immediately behind the crew compartment is an airlock with overhead docking port for transfer of crew and passengers between the orbiter and a space station or another orbiter. Two additional



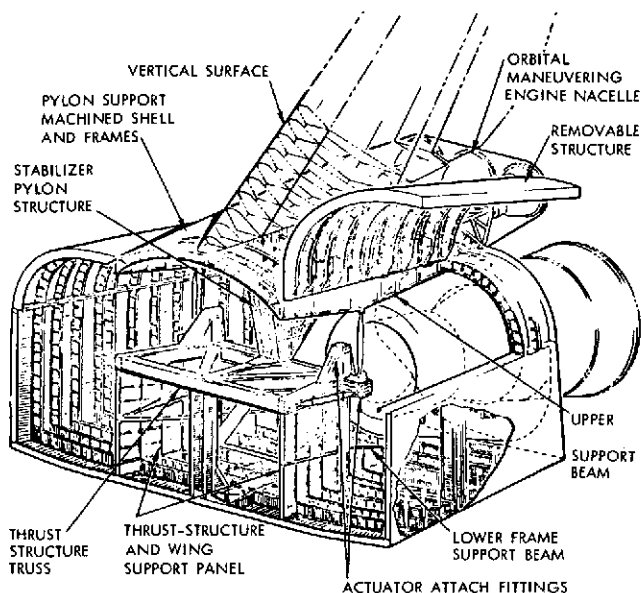
Orbiter Crew Module

passenger seats are installed in this area. The docking port is also used for general personnel access while the orbiter is on the ground and as an ingress-egress hatch during extravehicular activity in space. The aft section of the module serves as an electronics bay. A center aisle through the electronics bay contains four passenger seats and leads to a tunnel connected with the cargo bay. Ready passage in a shirtsleeve environment is provided between all manned compartments, including a habitable passenger module in the cargo bay, when used. Emergency egress for the crew and passengers is through overhead hatches.



Orbiter Center Body

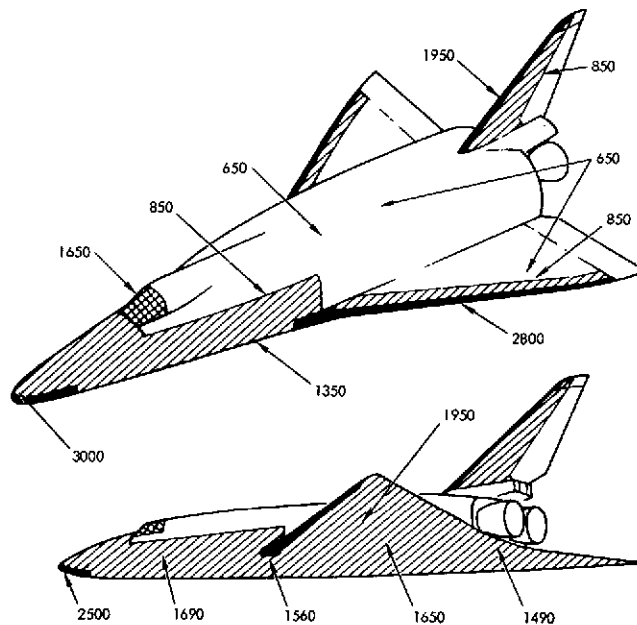
Somewhat elliptical in cross section, the orbiter center body carries two liquid-oxygen tanks for the main propulsion system, two liquid-hydrogen tanks for the orbital maneuvering engines, four deployable air-breathing turbofan engines, and cargo bay. The entire longitudinal midsection of the center body serves as a large unobstructed bay for the transport of payload modules. Hydraulically operated doors form a nonstructural cover and provide thermal protection for the cargo, which may consist of modules up to 15 feet in diameter and 60 feet long. Cylindrical propellant tanks are carried outboard of the cargo bay on either side. Immediately above the forward-mounted oxygen tanks are compartments for the four deployable, removable air-breathing engines.



Orbiter Aft Body

The aft body contains all mounting provisions for the two main rocket engines, three orbital maneuvering engines, and rear attitude control thrusters. Internal structures include wing support panels, thrust structure, and vertical stabilizer pylon.

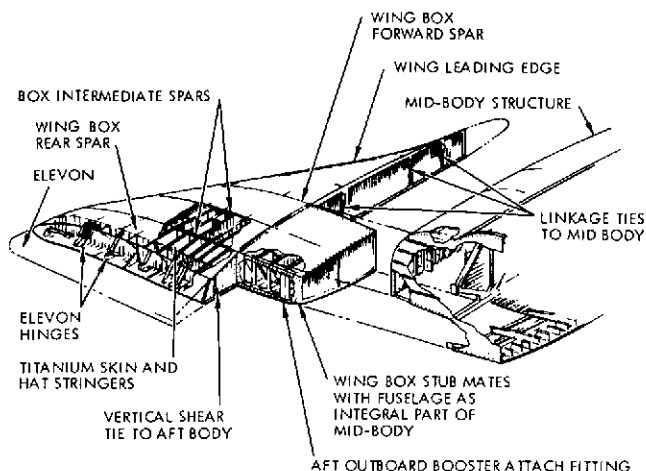
Most of the primary structures and skins throughout the orbiter are of titanium. Adequate heat resistance is provided by titanium in all areas not subjected to the direct thermal impact



Orbiter Thermal Protection Materials

of boost and reentry. Where severe heating occurs; namely, on all wing and fuselage undersurfaces, sides of the fuselage forward of the wing, upper portion of the wing leading edge, frontal area of the nose, and sides of the vertical stabilizer, supplementary surface protection is required. These areas are entirely covered with contoured refractory ceramic panels, which constitute the major element of the orbiter's reusable thermal protection system. Bonded directly to the titanium fuselage skin or to titanium carrier plates, the panels are made of a mullite matrix material coated with a refractory slurry on the outer surfaces and edges.

Where external skin temperatures are expected to exceed 2200 F, the design limit of protection offered by the mullite matrix panels, castings of reinforced carbon/carbon composite

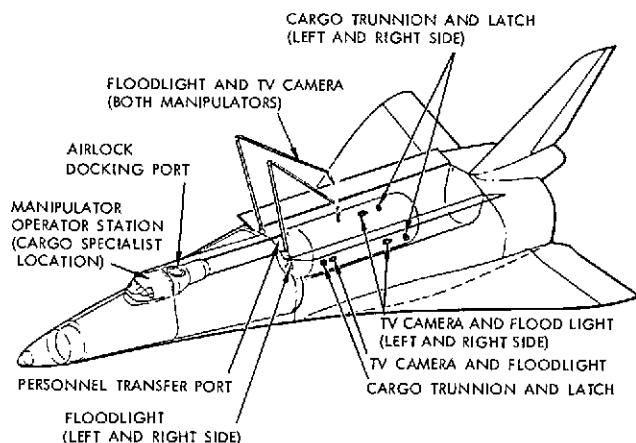


Orbiter Wing Structure

material are used. Mechanically attached to the substructure, this material is installed only on the extreme forward undersurface of the fuselage and on the leading edges of the wing and vertical stabilizer. Added protection for internal members supporting the carbon/carbon blocks is achieved with heat-absorbent zirconia blankets attached directly onto the structure.

The sixty-degree-sweep delta wing is blended with the fuselage at the forward edge to minimize shock wave interaction and to achieve uniform load distribution. Of multicell torque box construction, the wing includes provisions for stowage of the main landing gear and terminates in a full-span elevon on either side. All internal structures, as well as skins of both wing and elevon, are of titanium. Inner structures and skins of the fifty-degree-sweep vertical stabilizer and rudder are also of titanium.

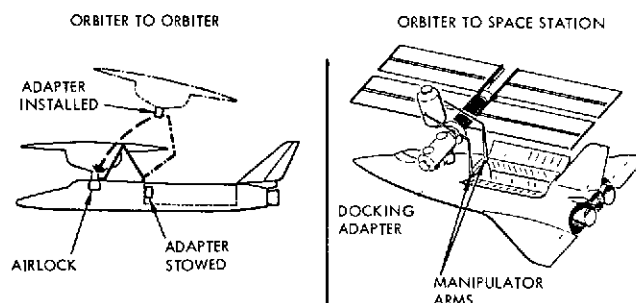
The orbiter's docking and cargo-handling system is designed to carry out the many



Docking and Cargo Handling System

unique functions associated with orbital operations and the manipulation of a variety of payloads in zero-gravity. Major elements of the system are the cargo storage, restraint, and maintenance provisions; cargo handling subsystem, and docking subsystem.

The cargo bay is fitted throughout with mechanical fasteners, trunnions, latches, and other restraints for securing a wide variety of payloads. It is also equipped with floodlights and closed-circuit television monitors placed to achieve maximum visibility in all parts of the hold. The two full-length, hydraulically actuated cargo doors, when opened, permit completely unobstructed vertical loading and removal of payload packages.



Docking Operations

Loading, unloading, and critical positioning of cargo modules is performed with a pair of jointed, electrically operated manipulator arms located on either side at the forward end of the cargo bay. Stowed inside the cargo compartment when not in use, the arms can be elevated, rotated, and extended to all corners of the hold. Precise control of the manipulators is exercised by a cargo specialist. The operator's station is equipped with all necessary television displays, communications outlets, and controls for maneuvering and emplacement of payloads.

The manipulators, in addition to serving as cargo-handling devices, perform a critical function during orbiter docking maneuvers. With the orbiter and the docking body stabilized at a distance of 25 to 50 feet, the arms are used to grasp the inert body, draw the two craft together, and mate their docking ports. When docking is performed with a space station or with another orbiter, as in a rescue mission, the manipulators are used to install a docking adapter before closure is performed.

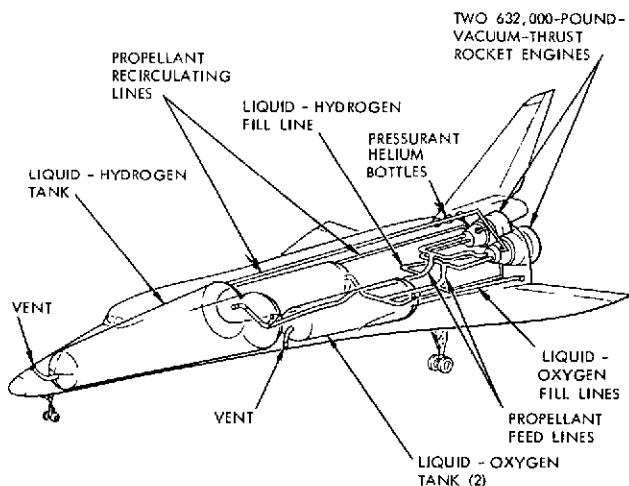
Among the specialized payloads to be carried aboard the orbiter are a habitable module, orbital maneuvering system auxiliary propellant kit, and thirty-day mission extension kit.



The habitable module is designed to sustain ten passengers for a period of seven days and may also serve as a manned laboratory for orbiter-based space experiments and earth surveys.

Orbiter propulsion is provided by four separate systems: the main rocket engine system for boost from separation to initial orbit, the orbital maneuvering system for orbit changes and deorbiting, the jet thruster system for exoatmospheric and entry attitude control, and the air-breathing turbofan engine system.

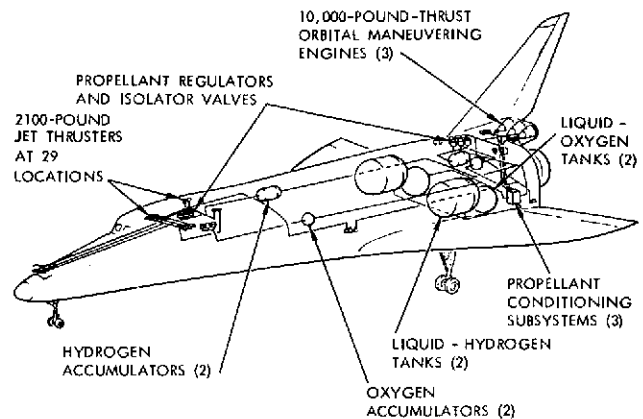
The main propulsion system consists of two rocket engines having powerheads identical to those used on the shuttle booster vehicles; however, thrust of 632,000 pounds each is achieved in vacuum by the addition of a retractable nozzle extension. Withdrawn into the engine compartment for aerodynamic protection during the launch and entry phases, the nozzles are extended shortly before orbiter engine start and retracted when the main engines are shut down.



Orbiter Main Propulsion

Liquid hydrogen is fed to the main engines from the integral fuel tank in the forward fuselage, while liquid oxygen is drawn from the two tanks in the center body. These propellants are delivered in a ratio of six to one through vacuum-jacketed manifolds, which separate into individual engine feedlines in the aft engine compartment. The forward liquid hydrogen tank is internally coated with spray-on foam insulation. The liquid oxygen tanks, however, do not require insulation.

Main engine ignition, propellant delivery, mixture ratio, and shutdown are controlled by a digital computer mounted on the engine assembly. Thrust-vector control is provided by engine gimbaling up to ± 7 degrees in yaw and ± 4.5 degrees in pitch.

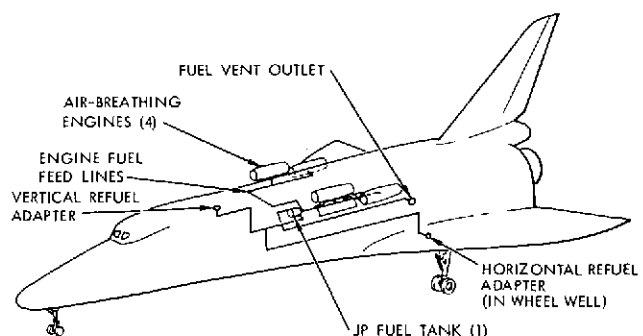


Auxiliary Propulsion System

Propulsion from the initial orbit established with the main engines is accomplished with three 10,000-pound-thrust rocket engines mounted in the rear compartment just above the main engines. Using liquid hydrogen and liquid oxygen, these engines draw propellants from independent tankage installed in the aft section of the vehicle. They also deliver thrust for circularizing orbits, establishing new orbits, rendezvousing, and ejecting from orbit for descent.

Attitude control is maintained on orbit and during reentry by 29 thrusters located at effective points near the fore and aft ends of the fuselage. These 2100-pound-thrust jets provide precision stabilization of pitch, roll, and yaw and are essential to maintaining proper orientation for lateral crossrange maneuvering during reentry. They also may be used as a backup deorbit system. The attitude control propulsion system and orbital maneuvering system, jointly referred to as the auxiliary propulsion system, draw their propellants from common tankage.

The orbiter's air-breathing engine system employs four high-thrust-to-weight-ratio turbofan engines carried in separate compartments atop the fuselage center body. Deployed in a staggered configuration at 35,000-foot altitude



Air-Breathing Engine System

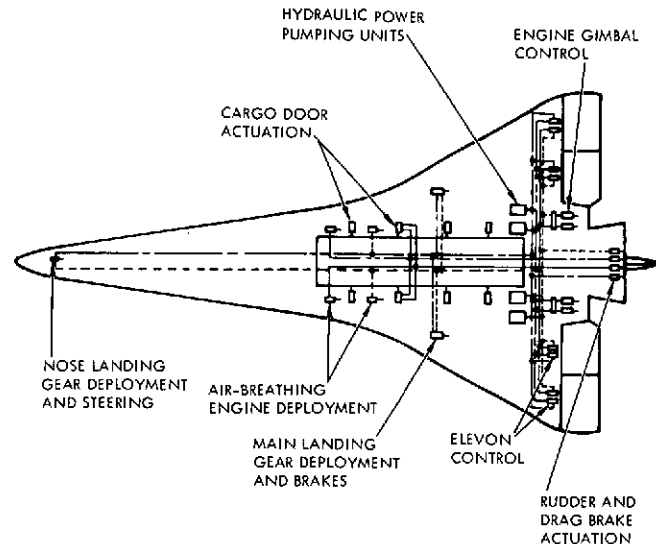


following reentry, their purpose is to provide go-around flight capability and to maintain altitude control during final descent and landing. With the addition of a fifth engine beneath the fuselage, the air-breathing engine system provides the orbiter with unassisted horizontal takeoff and flight capability for ferry flights and return to the launch site from alternative landing sites. JP fuel for the turbofans is carried in a single tank mounted ahead of the left forward engine compartment. An auxiliary tank is installed when long-range aerodynamic flights are to be made. Total weight of the engine system and fuel is about 18,000 pounds, which, if required, can be exchanged for additional payload by removing the engines and executing a full glide return and unpowered landing.

Both electrical and hydraulic power are supplied by four 195-horsepower auxiliary power units. Installed below the main engines in the aft fuselage, these turbine-driven units, each with an integral a-c generator and pump, derive gaseous hydrogen and oxygen propellants from the auxiliary propulsion system aft gas accumulators. The a-c generators provide supplementary electrical power during launch, approach, and landing only, the orbiter's fuel-cell power plants being the primary power source during on-orbit operations. Short-duration emergency electrical power is obtainable from batteries in case of auxiliary power unit or fuel-cell malfunction. The batteries are rechargeable from the fuel cells.

The three 7/10-kw orbiter fuel cells, located in the forward fuselage adjacent to the crew compartment, provide primary 28-volt d-c power via three central main d-c buses. Primary 115/200-volt, three-phase, 400-Hz, a-c power is produced by three 20/30-kva a-c generators and distributed through three main a-c buses.

Hydraulic power from the 60-gallon-per-minute, 4000-psig pumps on the auxil-

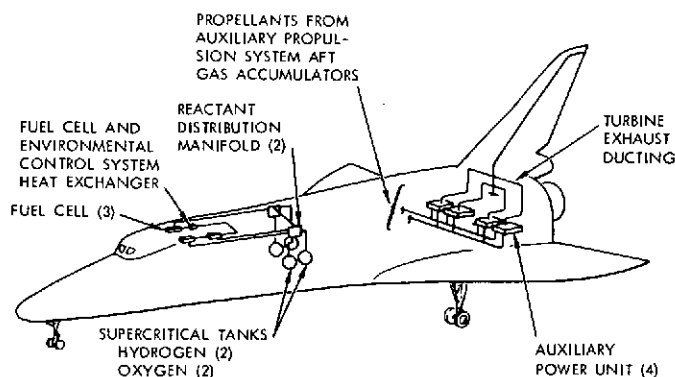


Hydraulic System

ary power units is transmitted through four independent, redundant distribution systems. Actuators powered by the system include those for aerodynamic control surfaces, engine thrust vector control, landing gear, air-breathing engine deployment, cargo bay doors, and main engine controls. The system is designed to assure full mission capability after a single failure and safe flight and return following a second failure regardless of the maneuver in progress at the time of the second failure.

Orbiter environmental control and life-support systems are dictated by the basic shuttle mission requirement: to maintain a shirt-sleeve environment for a crew of four for seven days or for thirty days with extra consumables. The overall system ensures appropriate environmental control for manned areas as well as equipment bays. Environmental maintenance of electronics and other sensitive equipment is essentially limited to temperature regulation and heat dissipation; however, extended closed-system preservation of human occupants involves numerous critical environmental and support considerations. Among these life-support functions are control of temperature, humidity, air composition, air pressure, contaminants, bacteria count, odors, ventilation, and acoustics.

Air temperature within the manned compartments is maintained between 65 and 75 F under normal conditions and between 40 and 110 F during emergencies. Atmospheric temperature control is achieved with a heat exchanger and fan units through which cooled or heated water is circulated. The same water-loop subsystem also



Power Generation System



supplies cooling water to the avionics compartment coldplates. Avionics coldplates in unpressurized locations are cooled by the freon-loop subsystem. Cabin air pressure may be selected at any point between 10 psi and one atmosphere, depending on mission mode.

Gaseous and liquid wastes may be disinfected and dumped overboard, while solid wastes are decontaminated and retained in onboard storage tanks for removal during ground maintenance. Air contaminants, including bacteria, particulate matter, and odors, are removed from the cabin atmosphere with filters.

Food management incorporates a food packaging system of protective overcans for storage of food serving cans, dehydratables, and drink packages. A unique freezer-locker compartment was conceived for food storage. The simple locker used for the seven-day mission is readily replaceable with a freezer for use on extended missions.

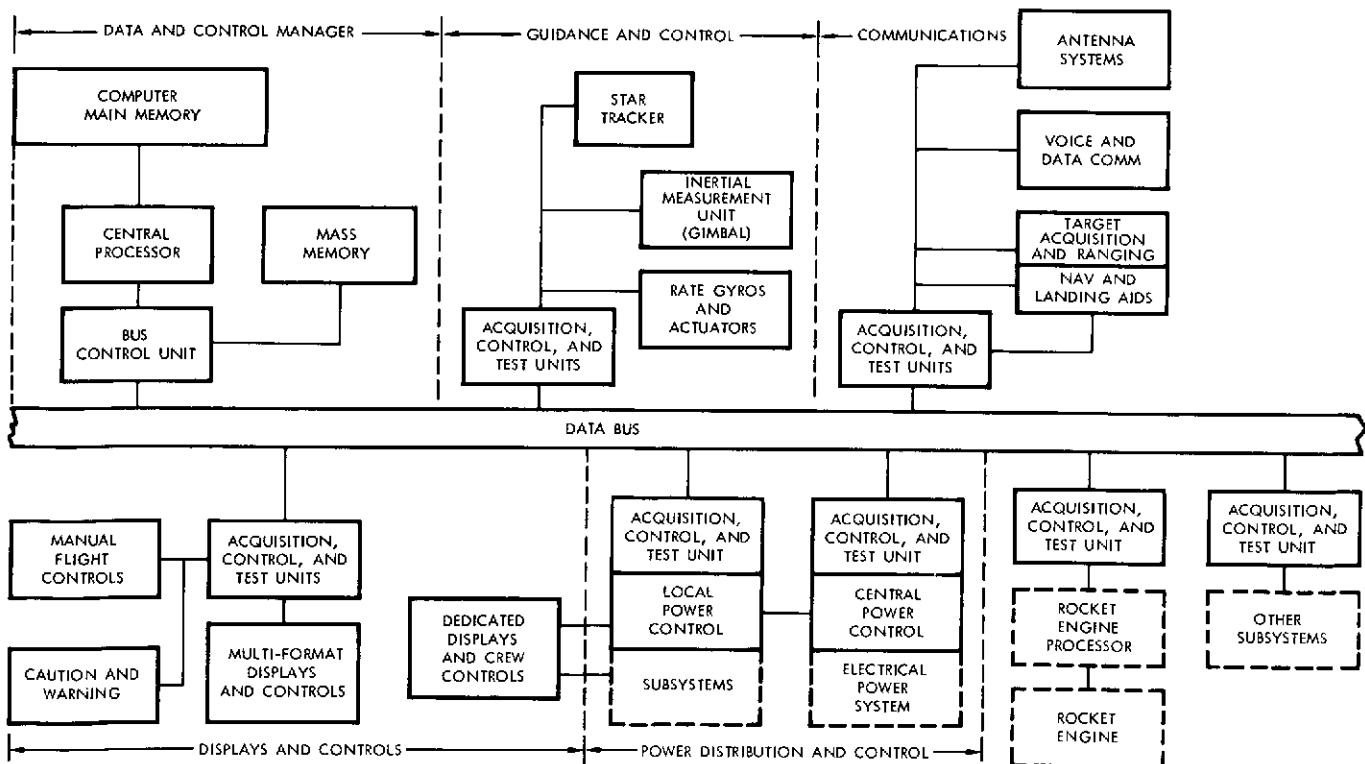
The integrated avionics system is essential to coordinated operation of all orbiter flight systems. Because of the comprehensive control exercised by the central data and control management computer, the total avionics system encompasses a number of elements formerly treated as separate electronic and electrical entities.

Major subsystems governed by the data and control management system are guidance and navigation, communications, displays and controls, and power distribution and control. This system also performs the critical function of onboard checkout and fault isolation, which is essential to achievement of rapid vehicle turnaround.

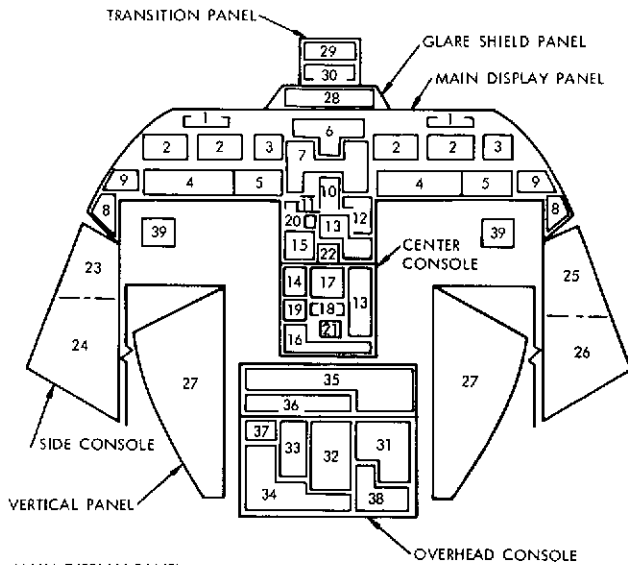
Computer inputs are received from the crew and from more than 5000 sensors throughout the orbiter. Coordinated control outputs are distributed via the main data bus to the crew display panels and to all flight systems.

Sensor inputs for guidance and navigation are derived from three independent units: the inertial measurement unit, star tracker, and precision ranging system with onboard transceiver and ground and space station transponders. The inertial unit is the primary navigation subsystem, the star tracker and ranging system serving as corrective devices only.

The displays and controls subsystem is centered in the commander's and pilot's consoles. Instrumentation of these panels consists of advanced units available from commercial, military, and space vehicle applications. Both graphic and alphanumeric representations indicate current system status, predicted conditions, and alternative procedures. All routine system activa-



Integrated Avionics System



1. EVENT TIMER
2. MULTIFORMAT CATHODE RAY TUBE DISPLAY
3. ALPHANUMERIC MESSAGE PANEL
4. DISPLAY SELECT CONTROLS
5. COMPUTER ENTRY KEYBOARD
6. BACKUP FLIGHT DISPLAYS
7. BACKUP FLIGHT DISPLAYS
8. LIGHTING CONTROLS
9. TIMER CONTROLS

CENTER CONSOLE

10. EVENT STACK
11. SURFACE POSITION INDICATOR
12. FLIGHT CONTROL MODE SELECT
13. FLIGHT CONTROL OVERRIDES
14. LANDING GEAR AND DRAG CHUTE
15. SECONDARY FLIGHT CONTROLS
16. COMPUTER AND DISPLAYS CONTROLS
17. MAIN THROTTLES
18. BACKUP THROTTLES
19. ROLL AND YAW AERO TRIM
20. FLIGHT CONTROL AND AIR DATA
21. FLIGHT CONTROLLERS CONTROLS
22. TRANSLATION CONTROLLER

LEFT SIDE CONSOLE

23. ENVIRONMENTAL CONTROL COOLANT CONTROLS
24. FUEL CELL AND CRYOGENIC CONTROLS

RIGHT SIDE CONSOLE

25. MAIN PROPULSION CONTROL
26. AUXILIARY PROPULSION CONTROL

VERTICAL PANELS

27. POWER DISTRIBUTION AND SWITCHING

GLARE SHIELD PANEL

28. CAUTION AND WARNING

FORWARD PANEL

29. CHECKOUT AND FAULT - ISOLATION READOUT
30. MISSION AND GREENWICH-MEAN-TIME TIMER

OVERHEAD CONSOLE

31. ENVIRONMENTAL CONTROL ATMOSPHERE CONTROLS
32. AIR-BREATHING ENGINE CONTROLS
33. AUXILIARY POWER AND HYDRAULIC CONTROLS
34. COMMUNICATIONS CONTROLS
35. ELECTRICAL POWER DISPLAY AND CONTROL SUBSYSTEM CONTROLS
36. FIRE PROTECTION
37. EXTERNAL LIGHTING
38. PYROTECHNIC CONTROLS
39. ROTATION CONTROLLERS

Orbiter Displays and Controls

tion and adjustment are automated; however, manual override capability exists for all critical functions.

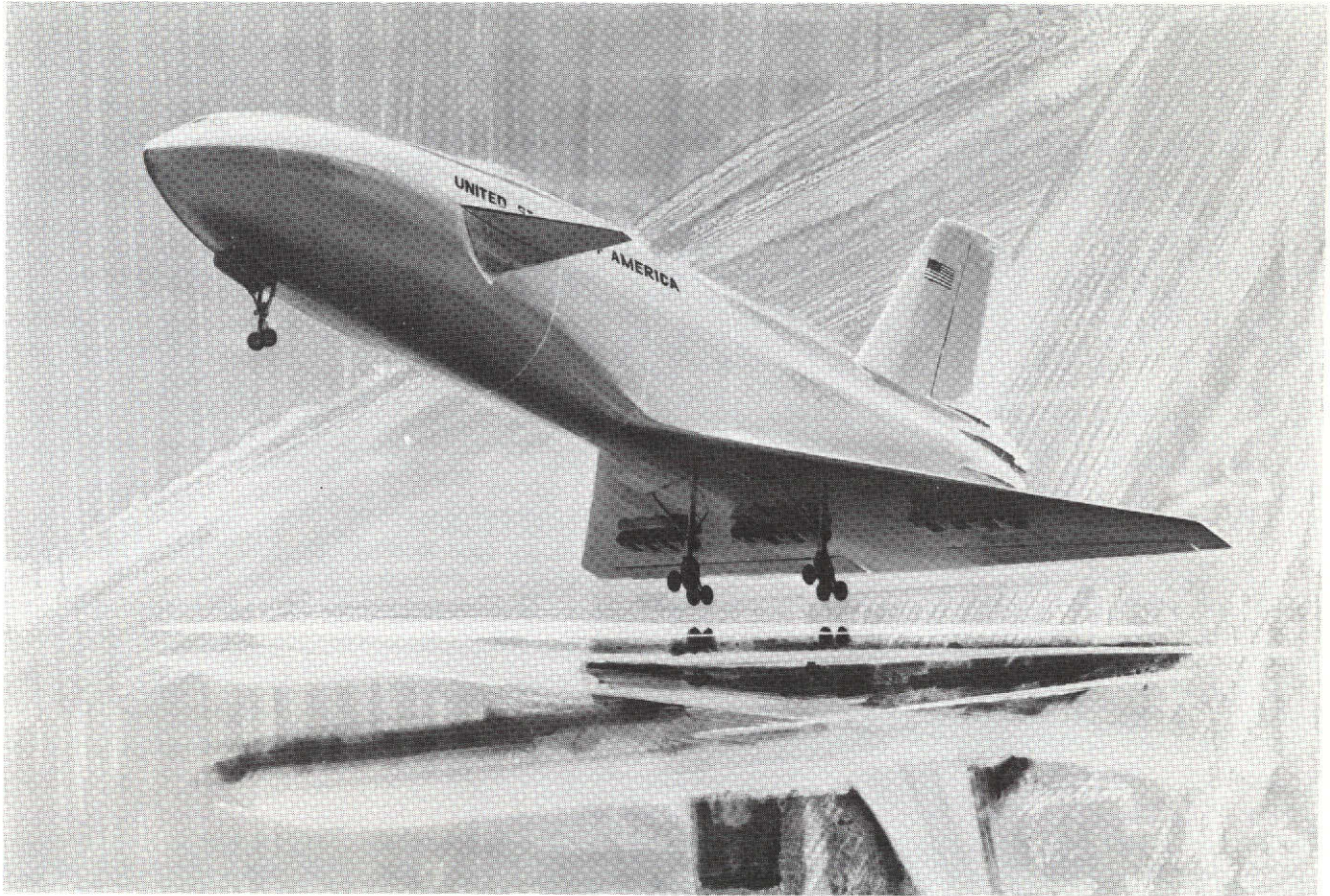
The orbiter communications subsystem provides two-way voice and data transmission, range and range-rate data for space rendezvous, and information for atmospheric navigation and landing. Performance of these functions requires a number of conventional and advanced electronic elements including transmitters, receivers, ground and spaceborne transponders, radar systems, and specialized antennas. A unified S-band system similar to that developed for Apollo provides primary onboard voice and data intercommunication as well as two-way transmission with the space station and the manned spaceflight network. Additional voice and data communication with the ground is accomplished with a VHF FM system via a stationary communications satellite, while two-way simplex voice transmission with civil and military air traffic control stations and with the booster vehicle is performed with UHF AM equipment. Precision ranging system interrogators provide data for cooperative-target range and range-rate determination, on-orbit state vector updating, and atmospheric navigation and landing. A radar altimeter is part of the precision ranging system. Fifteen flush-mounted antennas are installed at various points on the orbiter fuselage. Antenna selection, as well as overall system checkout and control, is accomplished by the central data and control management system. Manual override provisions for all elements of the communications subsystem are incorporated.

The Booster Vehicle

The booster described at the end of Phase B is a 269-foot-long, approximately four-million-pound, delta-wing vehicle equipped with twelve rocket engines for launch and twelve air-breathing turbofan engines for atmospheric cruise back to the launch site.

Manned by a commander and pilot, the vehicle is aerodynamically controlled with a pair of movable canards located somewhat forward of center and with conventional elevons and rudder on the trailing edges of the wing and vertical stabilizer. Attitude control when above the atmosphere is maintained with a system of rocket thrusters. Landings are made on a typical large airport runway using aircraft-type landing gear.

Reusable heat shielding is installed over all external surfaces to resist the high temperatures encountered during boost and reentry, while



Shuttle Booster

an environmental control system and appropriate insulation are employed to regulate internal temperatures.

General arrangement of the booster vehicle is dictated by four factors: achievement of airline-type vehicle design and operational characteristics, accommodation of large volumes of propellant, controlled atmospheric and exoatmospheric flight, and support of the orbiter.

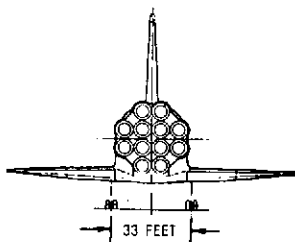
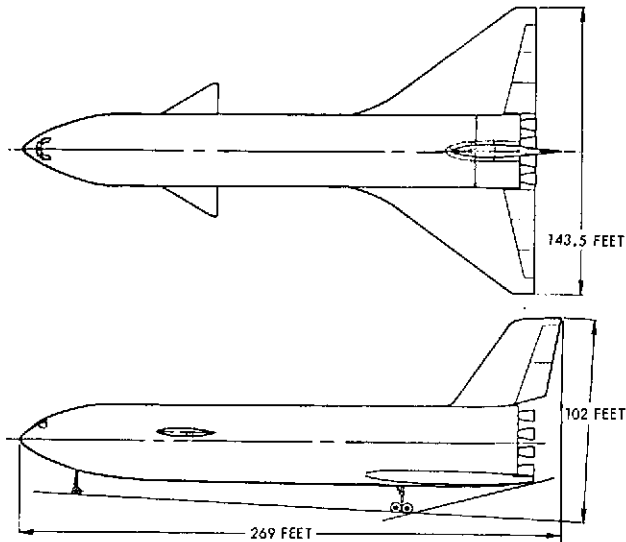
The environmentally controlled crew station is a pressurized module containing a forward flight deck and aft avionics bay. Flight control instrumentation is arranged for comprehensive display of all critical flight information to both commander and pilot. Access to the crew compartment while the booster is in a horizontal position on the ground is via a series of ladders through the nose wheel well and leading to a hatch in the floor of the avionics bay. Crew members boarding or leaving the vehicle after it is erected for launch, however, pass through a side hatch, which is accessible from a loading arm on the launch umbilical tower. Emergency egress from the

erected booster is through the side hatch to a rapid-descent elevator system that carries personnel to an underground shelter.

The major portion of the booster fuselage consists of liquid oxygen and liquid hydrogen tankage. A 305,000-gallon liquid-oxygen tank is located behind the crew compartment and is connected with the rocket engines by insulated feed lines running through a ventral channel. The area between the rear of the oxygen tank and the engine compartment is occupied by a 33-foot-diameter, 880,000-gallon liquid hydrogen tank.

To facilitate manufacturing, the booster fuselage is fabricated in five major structural assemblies: forward skirt, liquid-oxygen tank, intertank adapter, liquid-hydrogen tank, and aft thrust structure with engine heatshield. The two main tanks are designed to incorporate all necessary fuselage structural members; thus, they can be produced as complete fuselage sections.

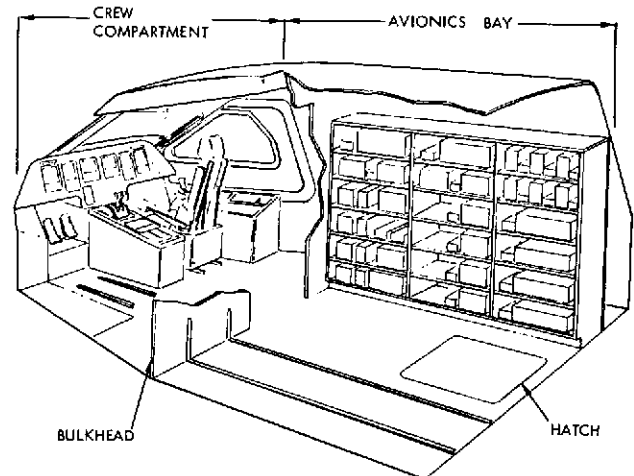
Because the body structure is protected from aerodynamic heating by an external thermal protection system, all fuselage



Booster Configuration

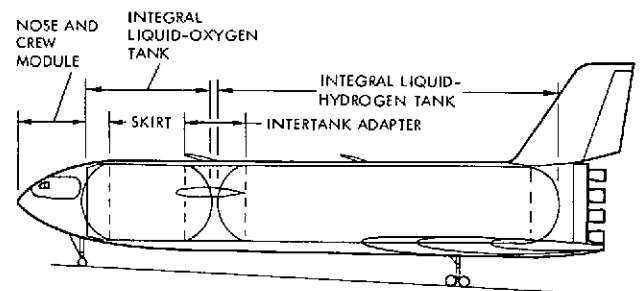
members, except the aft thrust structure and heatshield, are of aluminum alloy. The thrust structure is of titanium alloy and aluminum-boron materials. The engine heat shield is of high-temperature-resistant coated columbium and René 41.

Design of the delta wing provides a fail-safe structure of multiple spar and rib construc-



Booster Crew Station and Avionics Bay

tion. The two primary wing boxes are attached to an under-body carry-through structure. All wing and elevon structural members, as well as the corrugated skins on the upper surfaces are of titanium. Undersurfaces are thermally protected with shielding of HS 188 steel and coated columbium, while the hot leading edge of the wing is all coated columbium.

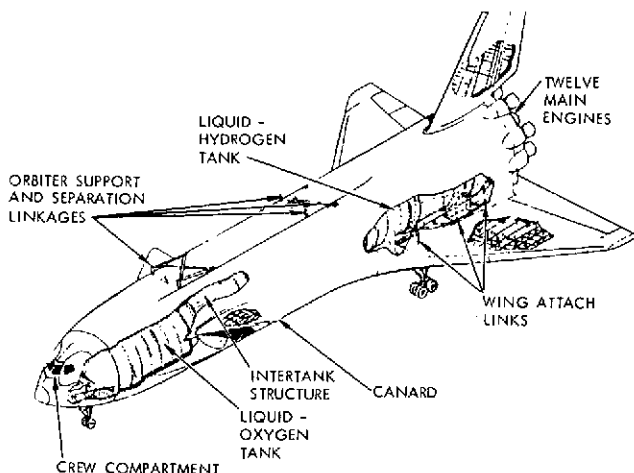


Booster Main Tank Arrangement

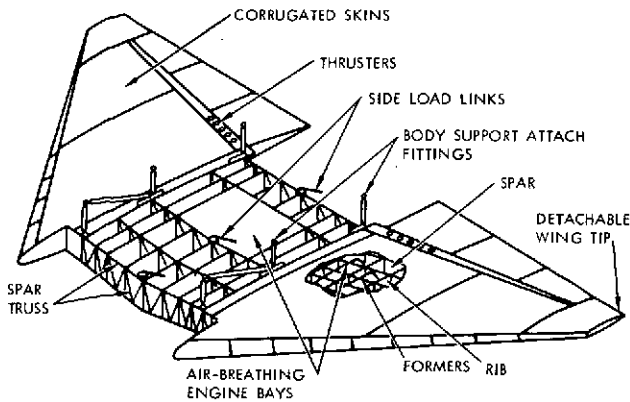
Construction of the vertical stabilizer and rudder is similar to that of the wing and elevon. Titanium is used throughout, except for the leading edge, which is of Inconel 718 steel and René 41 to afford protection from both aerodynamic heating and orbiter engine exhaust.

The fully movable canards are supported by pivot tubes extending from the intertank structure. Construction of the canard box is again similar to that of the wing. Internal members are of titanium; however, the upper and lower surfaces are protected with René 41, and the leading edge with carbon/carbon composite.

The most advanced feature of the shuttle booster is its thermal protection system, which shields the internal structures from the intense heat of boost and reentry. This unique

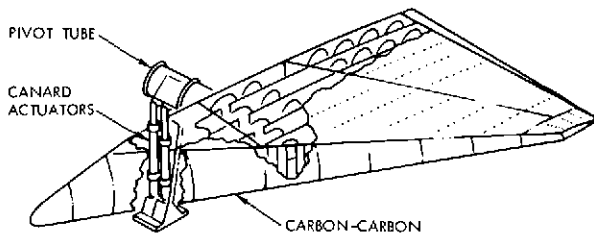


Booster General Arrangement



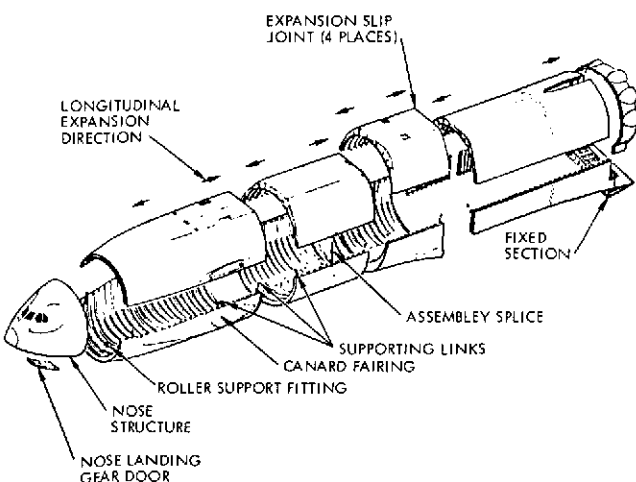
Booster Wing Structure

structure is designed to accommodate the large thermal displacement of materials encountered throughout the fuselage as a result of the very low internal temperatures emanating from the cryogenic tankage and the very high external temperatures generated during boost and reentry. Consisting of a separate stiffened shell that surrounds



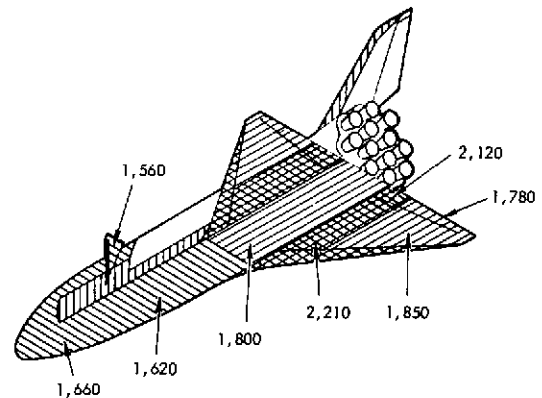
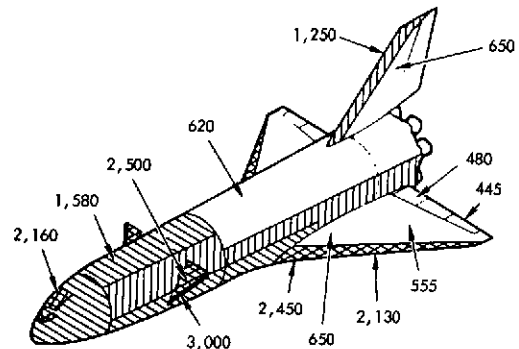
Movable Canard

the primary fuselage structures, the system is composed of a series of contoured heat-resistant metallic segments. The entire shell is rigidly attached to the primary structure at four frames. In addition, a system of swinging links is used to



Booster Thermal Protection System

attach the shell at points where differential expansion occurs between the shell and the underlying primary structure. Peripheral slip joints permit telescoping of the shell to compensate for longitudinal expansion of the major segments. Materials used in the fuselage thermal protection system are selected, as are those for the aerodynamic control surfaces, according to the temperature levels encountered at various points on the vehicle.

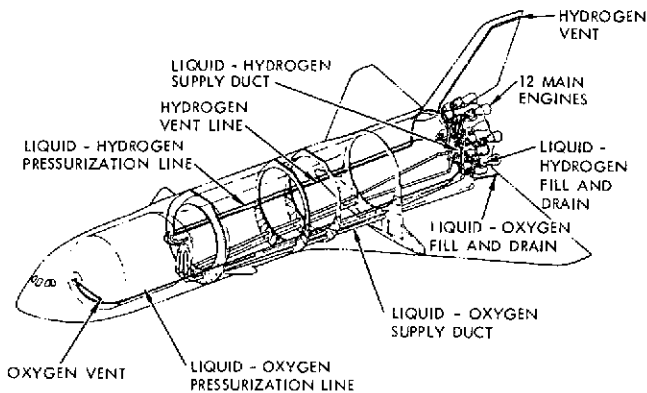


TITANIUM	RENE 41
INCONEL 718	HS 188 STEEL
REINFORCED CARBON-CARBON	COATED COLUMBIUM

TEMPERATURES IN DEGREES FAHRENHEIT

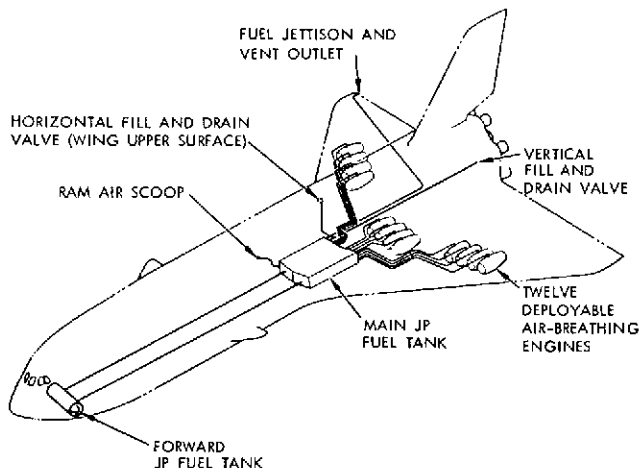
Booster Thermal Protection Materials

Propulsion of the mated vehicles from liftoff through separation is provided by the booster's twelve 550,000-pound-thrust-liquid-propellant rocket engines. Mounted in a cruciform cluster at the rear of the booster, the engines are controlled by an engine-mounted digital computer that responds to start, shutdown, propellant mixture, and thrust-level commands. Vehicle boost trajectory is maintained by a thrust-vector control system that gimbals the engines up to ± 10 degrees. Liquid hydrogen and liquid oxygen are delivered to the engines from the main tanks at a ratio of six to one.



Booster Main Propulsion System

Thrust required to power the booster during airborne cruise back to the launch site is provided by an air-breathing turbofan engine system consisting of twelve engines mounted in three groups of four engines each. In addition to maintaining vehicle propulsion and control during level flight and landing descent, the turbofans deliver sufficient power for horizontal booster takeoff, a capability required for ferry flights between launch sites and for return from alternative landing sites. Four nacelles are stowed in each

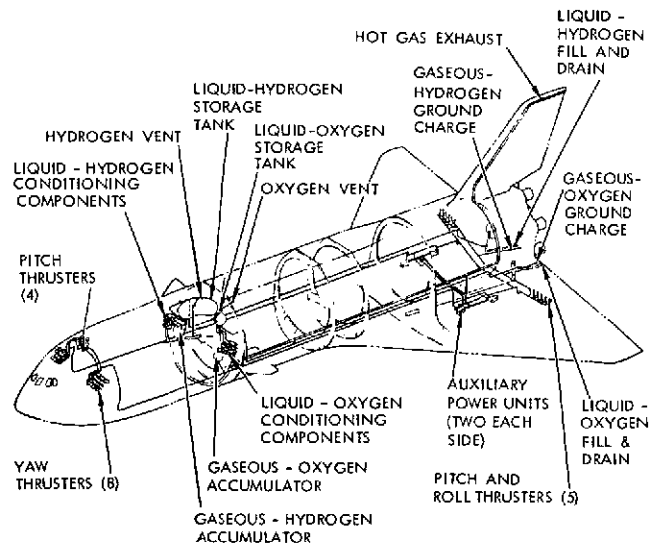


Air-Breathing Engine System

wing and four are stowed in the wing carry-through section. After reentry, the engines are deployed beneath the wing structure and started. JP fuel for the turbofans is carried in dual tanks located beneath the main liquid-hydrogen tank and in the nose compartment.

The auxiliary propulsion system consists of thirty jet thrusters, each developing 2100 pounds of thrust. It is used to stabilize the booster in pitch, roll, and yaw following main rocket engine shutdown. This mode of attitude control is sustained until the aerodynamic surfaces

become effective during reentry. A bank of eight yaw engines is located on each side of the fuselage just aft of the pilots' compartment. Another four located in the top of the fuselage in the same area are directed upward to control pitch. A bank of five thrusters is also installed in each wing just forward of the elevon. Directed upward, they provide pitch-up control when fired simultaneously or roll control when fired on one side only. The thrusters are fueled with gaseous oxygen and



Auxiliary Propulsion System

hydrogen fed by a propellant-conditioning system that draws from separate hydrogen and oxygen tanks rather than from the main propellant tanks.

Also using gaseous propellant supplies from this system are the four auxiliary power units. Mounted inside the wing carry-through structure, they are operated continuously and together provide all booster hydraulic pressure and electrical power. Each unit consists of an integrated gas turbine, gear box, hydraulic pump, and electrical generator. A 687-horsepower turbine simultaneously drives the pump and generator in each unit. The hydraulic pump delivers 247 gallons per minute at a pressure of 4000 psig. Hydraulic power is distributed through four independent circuits to all actuators for rudder, elevon, and canard control; landing gear extension; and air-breathing engine deployment.

The electrical generator delivers three-phase, 20/30-kva, 120/208-volt, 400-Hz, a-c power continuously at 30 kva or at 40 kva for five seconds. This power is distributed to the forward and aft distribution centers via three main busses. D-c power is obtained from transformer-rectifiers located at the distribution centers. Two nickel-



cadmium batteries, each rated at 10 ampere-hours, are included as elements of the d-c system to provide backup power in case of total power loss.

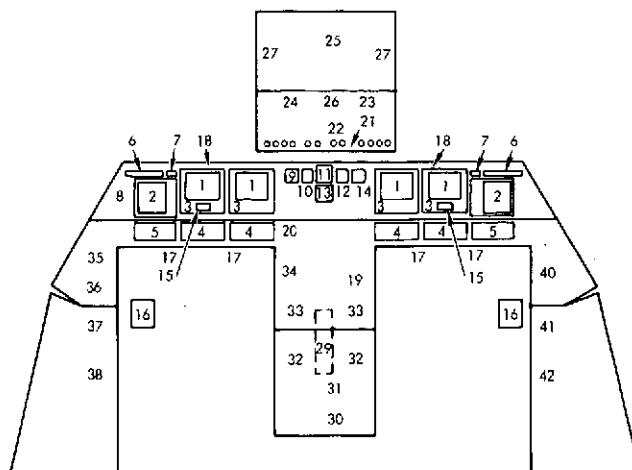
Because of the short duration of booster operation from liftoff through boost, exoatmospheric activity, and reentry, the on-board environmental control requirements for crew and avionics are minimal. The need for cabin air purification, air composition, and humidity control are eliminated; and maintenance of a shirtsleeve environment is possible with temperature and pressure control only. Cabin pressure of 8 psia is held with aircraft-type pressure regulators. Separate safety valves prevent overpressure.

The integrated avionics system aboard the booster, in contrast to that of most other types of aircraft, is an essential element of all flight operations. During ascent and reentry, some nineteen booster subsystems are involved in a series of rapidly changing modes that can be precisely sequenced and coordinated only by automatic control. In conjunction with the crew, the avionics system performs functional management and control of all critical operational vehicle subsystems. Overall coordination is accomplished by the data and control management subsystem. Other primary elements of the integrated avionics system are displays and controls; guidance, navigation and flight control; communications; and electrical power distribution and control. A major capability of the total system, in addition to its monitoring and control function, is on-board checkout and fault isolation, a particularly valuable feature in the achievement of rapid vehicle turnaround.

The data and control management subsystem receives commands from the crew and more than 7000 inputs from vehicle monitoring sensors located throughout the booster. By means of its data management computer, the information

is processed and analyzed and distributed through the main data bus to the crew and vehicle subsystems.

Computer outputs are displayed to the crew in the form of caution, warning, and emergency signals and as specific statistical and



MAIN DISPLAY PANEL

- 1 MULTIFORMAT CATHODE RAY TUBE DISPLAY
- 2 ALPHANUMERIC MESSAGE PANEL
- 3 DISPLAY SELECT
- 4 MODE SELECT
- 5 COMPUTER ENTRY AND CONTROL KEYBOARD
- 6 TIME READOUT
- 7 MASTER ALARM AND EMERGENCY WARNING
- 8 ELECTRICAL POWER DISPLAY, DISPLAY SELECT, AND G METER
- 10 AUX. INDICATED AIRSPEED
- 11 AUX. ATTITUDE DIRECTOR INDICATOR
- 12 AUX. ALTITUDE (BAROMETRIC)
- 13 AUX. BEARING, DISTANCE, AND HEADING INDICATOR
- 14 AUX. RATE-OF-CLIMB INDICATOR
- 15 AUX. SLIP INDICATOR
- 16 ROTATION HAND CONTROLLER
- 17 RUDDER, NOSE WHEEL STEERING, BRAKES
- 18 ABORT LIGHT
- 19 ABORT PANEL
- 20 LANDING GEAR CONTROL

OVERHEAD PANEL

- 21 FIRE PROTECTION
- 22 CAUTION AND WARNING STATUS AND MODE CONTROLS
- 23 HYDRAULIC CONTROLS
- 24 ENVIRONMENTAL CONTROL DIRECT OXYGEN VALVE
- 25 FUEL MANAGEMENT AND AIR-BREATHING ENGINE DEPLOYMENT
- 26 ELECTRICAL POWER DISTRIBUTION
- 27 LIGHTING

CENTER CONSOLE

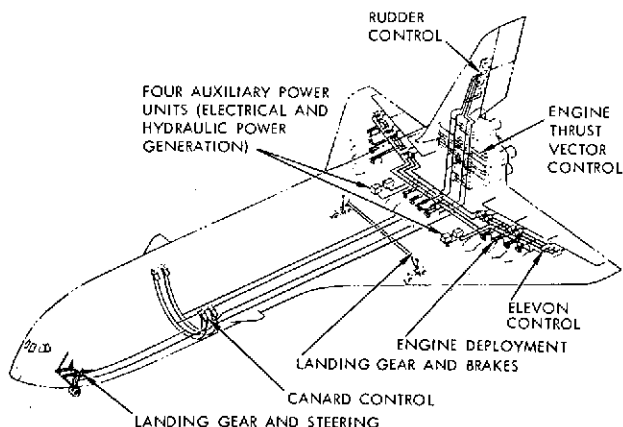
- 29 AIR-BREATHING ENGINE THROTTLES
- 30 COMMUNICATIONS CONTROLS
- 31 GUIDANCE AND CONTROL MODE SELECT
- 32 FLIGHT CONTROL SYSTEM CONTROL
- 33 CREW AUDIO PANEL
- 34 PARKING BRAKE HANDLE

LEFT SIDE PANELS

- 35 ENVIRONMENTAL CONTROL CONTROLS
- 36 ENVIRONMENTAL CONTROL DISPLAYS
- 37 CRYOGENIC CONTROLS
- 38 CRYOGENIC DISPLAYS

RIGHT SIDE PANELS

- 40 ATTITUDE CONTROL PROPULSION SYSTEM CONTROLS
- 41 MAIN PROPULSION SYSTEM CONTROLS
- 42 AUXILIARY POWER UNIT CONTROLS



Booster Hydraulic System

Booster Displays and Controls



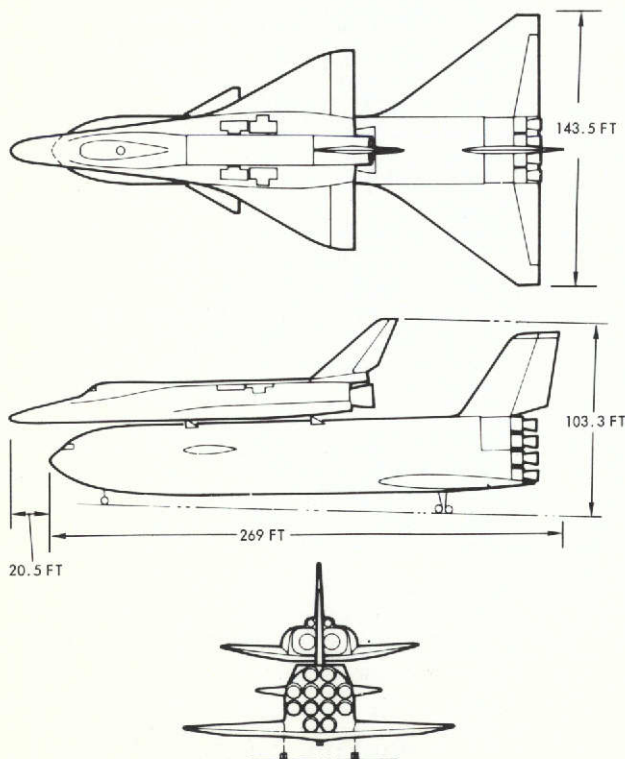
visual representations of normal booster status. The symmetrical crew station display and control consoles are arranged for full viewing and manipulation from either seat in the event of a flight emergency.

Booster communications subsystems provide, not only two-way data and voice exchange with the orbiter and ground stations, but a number of other electromagnetic transmission functions as well. Data for navigation, approach, and landing are acquired with a multifunction precision ranging system consisting of an interrogator, ground transponders, and radar altimeter. Atmospheric and altitude information are communicated via a conventional aircraft-type Federal Aviation Agency air traffic control transponder.

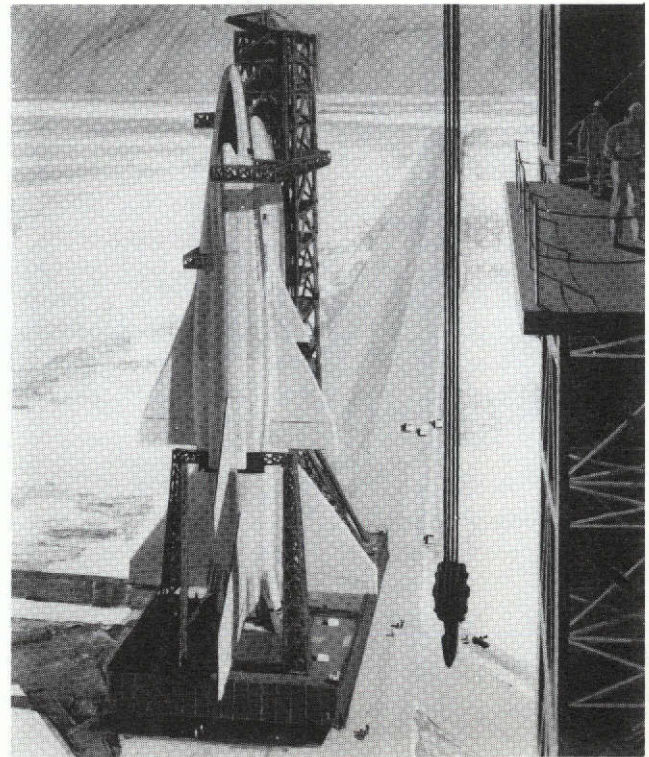
The Mated Vehicles

In the mated configuration, the vehicles form a vertical stack 290 feet tall - approximately 75 feet shorter than the Apollo-Saturn vehicle. The orbiter, which is attached at three points to the flat dorsal surface of the booster, extends about 20 feet forward of the booster nose.

Acting as a single vehicle throughout the ascent phase, the mated orbiter and booster are propelled by the booster's main engines



Mated Vehicle Configuration

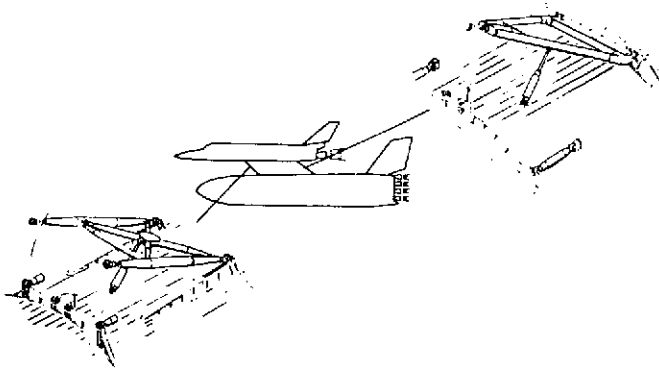


Mated Vehicles

to a separation altitude of approximately 40 miles and a velocity of about 6500 miles per hour. Acceleration during the 3½-minute ascent is limited to not greater than 3 g's by the booster's engine thrust control subsystem. With aerodynamic control surfaces of both vehicles in a passive mode, gimbaling of the main engines provides the necessary thrust vector control to maintain proper boost trajectory.

Primary flight control of the mated vehicles from liftoff through separation is directed by the crew and the data and control management system of the booster. Any of three hardwire communication and data links between the mated vehicles, however, may be used by the orbiter crew to initiate emergency separation.

Mounting and separation provisions for the orbiter vehicle consist of two catapult frames installed atop the booster and lying flat between the mated vehicles. The forward rectangular frame is attached at the rear to the booster structure only by a pivot joint at either side. The forward end of the frame provides two explosive-bolt attach points for the orbiter and is held down to the booster structure by explosive-bolt restraints. The rear catapult frame, which is triangular, provides a single orbiter attach point at the forward end and is similarly pivoted and con-



Separation System

strained. Separation is accomplished by the following sequence: Booster thrust is reduced; orbiter engines are started; and vertical hold-down restraints are disconnected. The still greater acceleration of the booster causes the catapults to rise at their forward ends and lift the orbiter. Links to the orbiter are then severed and full orbiter thrust is attained. As separation occurs, the booster engines are shut down. The entire computer-controlled separation sequence requires less than five seconds.

Vehicle Weight Summary (Pounds)

Item	Orbiter*	Booster
Structure	101,424	279,480
Thermal Protection	38,588	86,024
Propulsion	48,696	186,425
Mechanical and Power	9,226	15,433
Avionics	3,790	5,582
Crew System and Environmental Control	4,613	3,284
Growth	17,094	50,705
Dry Weight	223,431	626,933
Personnel	618	476
Payload	40,000	—
Residuals	4,022	11,503
Inert Weight	268,071	638,912
Reserves	6,463	—
Losses	5,995	21,718
Propellant		
Ascent	555,436	3,382,307
Cruise		143,786
Auxiliary propulsion system	23,139	1,500
Gross Weight	859,104	4,188,223

*Configured for 40,000-pound payload with air-breathing engines removed.

Launch Operations Complex

Recommendation of Kennedy Space Center (KSC) as the primary launch site for shuttle is based on its general superiority to other

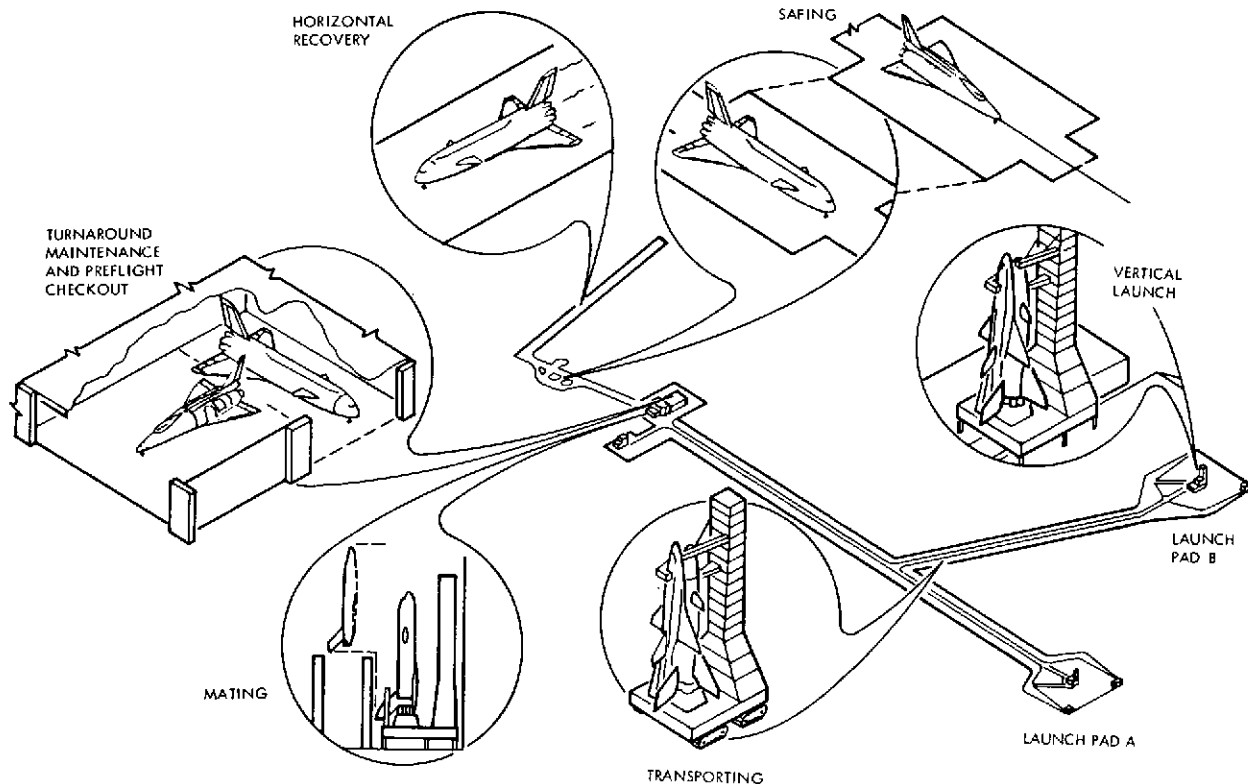
candidate sites considered during Phase B. Numerous existing sites across the United States were examined; of these, the six most promising were subjected to in-depth analysis from the standpoints of mission suitability, accessibility, population density, availability of skilled manpower, existing facilities, and modification costs. With the exception of the Western Test Range, which has a preferred location for south-polar launches, all but Kennedy Space Center were eliminated by trade study. The present vast array of large launch and service structures available at KSC offers a complete space shuttle ground complex with comparatively moderate demand for facilities modification and new construction.

Shuttle requirements at the launch site call for both dedicated and shared support functions. Inasmuch as heavy emphasis has been placed on commonality with existing systems, extensive shuttle support is available as needed from long-established NASA, DOD, and FAA facilities. Among the services obtained from these nondedicated sources are program mission planning and mission control, as well as offsite network communications, alternative landing and ferry sites, and search and rescue support.

Major dedicated facilities at the operations site consist of the landing strip, post-landing safing area and equipment, maintenance and checkout building, mating installation, mated-vehicle transportation system, and launch pad.

One of the few new installations required at KSC is a landing strip for the orbiter and booster in reasonable proximity to the maintenance complex. Safing, because it is an operation peculiar to the reusable shuttle vehicles, also requires new installations adjacent to the landing strip. Primary functions of the safing operation are crew, passenger, and flight data removal; cool-down of the exterior thermal protection system; and nitrogen purging of propellant tanks and feed lines. Equipment is required for unloading personnel and any cargo that cannot remain aboard during the safing period. Also needed are ground utility services for avionics cooling, air conditioning, pressure and vacuum sources and service lines, and electrical supplies. The most extensive system associated with safing is that required for remotely controlled purging of tankage and disposal of hazardous fluids. A single safing facility serves both booster and orbiter.

Maintenance and preflight checkout is carried out in the existing vertical assembly building (VAB) and in a new hangar adjoining the



Launch, Recovery, and Turnaround Complex

north wall of the VAB. The new hangar is required to accommodate the booster vehicle, orbiter maintenance being carried out inside the VAB. Minor modification of the VAB doors is required for exit of the mated vehicles. On arrival at the maintenance hangar, the vehicle is positioned, service stands are installed, and cargo packages are removed with overhead cranes and transported to their respective payload facilities. If deemed necessary, postflight checkout may be performed at this time. Preventive and corrective maintenance, as well as any required servicing, and modification are then accomplished, and the vehicle is secured for storage or released for immediate reuse.

An extensive assortment of ground service equipment is required for hangar maintenance; however, attention to commonality of test fittings in orbiter and booster design, and design of service equipment capable of a wide range of system performance measurements have reduced the need for many separate test systems and adapters. This philosophy has been applied wherever vehicle systems are to be serviced, from manufacturing through test and flight operations.

A full complement of ground conditioning, pneumatic, and power service outlets is needed in the maintenance hangar. In addition,

electronic and electrical checkout systems with automatic data acquisition and fault-isolation features must be provided. Again, the vehicle design approach has reduced the ground equipment requirements. On-board computer-controlled self-checkout and fault-isolation systems readily perform many functions formerly requiring special test devices and trained operators. Items of general mechanical equipment at the maintenance hangar include gantry cranes, jacking and handling gear, and precision alignment devices.

When the vehicles are assigned to a mission, payloads are installed in the orbiter and both vehicles are subjected to comprehensive pre-mate checkout. These functions are carried out in the maintenance hangar using much of the equipment employed during postflight maintenance and checkout operations. On satisfactory completion of subsystems checkout and verification of payload interfaces, the orbiter and booster interfaces are examined and the vehicles are released for mating.

The booster is first moved to the adjacent vertical assembly building (VAB), where it is hoisted to a vertical position and mounted on the transportable launch umbilical tower. The orbiter is then hoisted and brought into position on the back of the booster. Attach fittings are



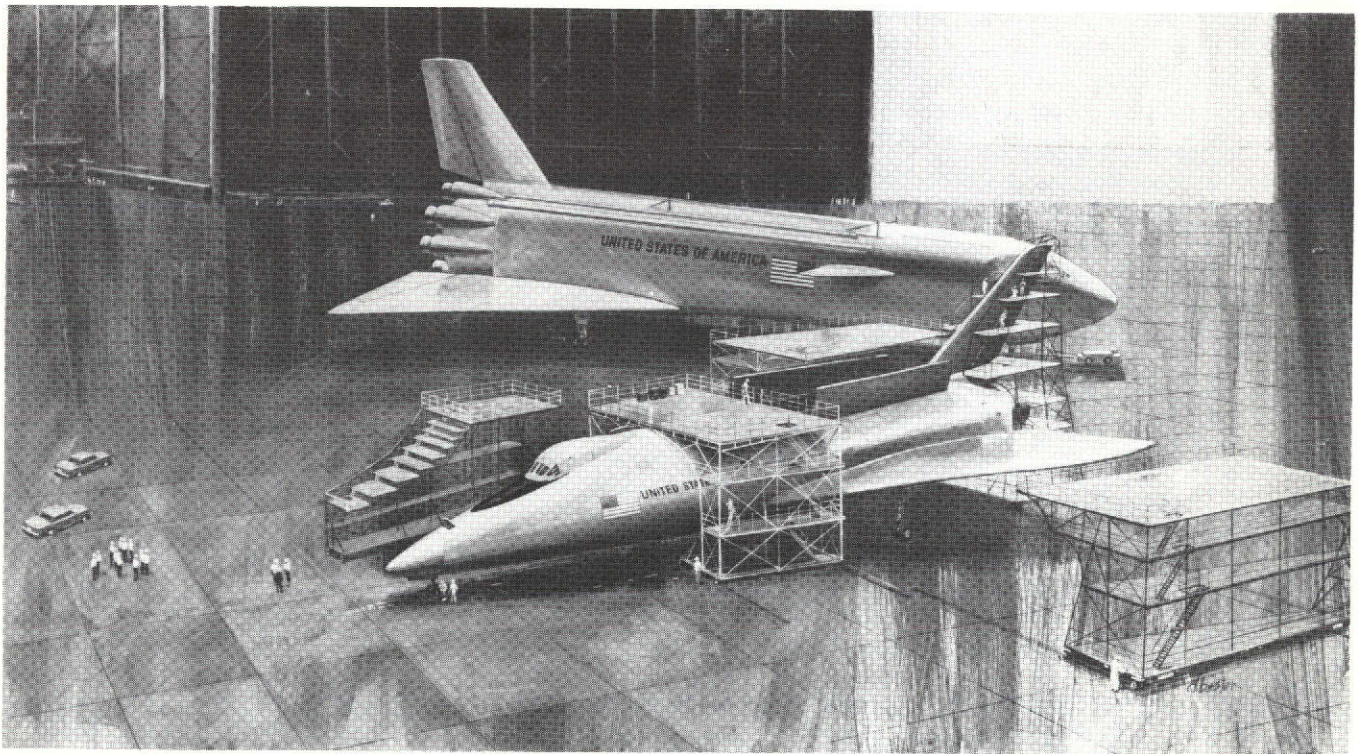
secured, launch tower umbilicals are connected, and the vehicles are transported to the launch pad.

Comparable size and weight of the shuttle and the Apollo-Saturn vehicles permit use of existing major VAB, transportation, and pad facilities modified as necessary to accommodate dimensional differences. Pad services, in addition to the normal ground conditioning, pneumatic, and power supplies, include data and remote control systems, and propellant loading.

Broad adoption of airline-type maintenance objectives has given the shuttle a degree of self-sufficiency far greater than that of previous space vehicles and has produced a system having on-board safety features and rapid turn-around characteristics that could not otherwise have been achieved. Particular cost savings inherent

in this approach are reflected in the reduction of complex independent items of ground service equipment needed.

The cursory system descriptions presented on the preceding pages are intended to provide a general overview of space shuttle design and performance features. Detailed analytical summaries, drawings, and engineering data defining each of the systems noted are given in NR Report SD 71-114-2, the *Technical Summary* of the *Phase B Final Report*. Published in four separately bound documents, the *Technical Summary* provides, not only the detail required to fully define the systems selected during the Phase B study, but includes engineering, manufacturing, facilities, and support equipment data substantiating the selections made and the technological advances identified.



Hangar Maintenance



PROGRAM COST AND SCHEDULE ESTIMATES

Constant effort was applied throughout the Phase B study to establish and maintain reliable estimates of program costs and schedules. Program plans were developed and continuously updated to identify major requirements and implementation approaches for shuttle engineering, manufacturing, facilities, testing, logistics, maintenance, operations, and management. The baseline program outlined by these plans served as a basis for estimation of the schedules and costs ultimately presented.

Cost factors were held as an element of primary importance in relating shuttle system requirements to shuttle development, production, and operations. During each trade study, the design and procedural options were examined to determine the most cost-effective approach within the limits of safety and performance.

The total cost in 1970 dollars for development of the orbiter and booster vehicles and for conduct of the operational program through 1989 is estimated at 9.64 billion dollars. Not included in this figure are costs of the main propulsion engine, passenger payload module, mission planning and simulation, horizontal flight test facilities, operational site facilities, and contractors' fees. It does cover delivery of an operational fleet consisting of four booster vehicles and five orbiter vehicles to accomplish the 445 missions set forth in the NASA-DOD traffic model projection.

This fleet size is adequate to support the two-week ground turnaround and 48-hour space rescue objectives.

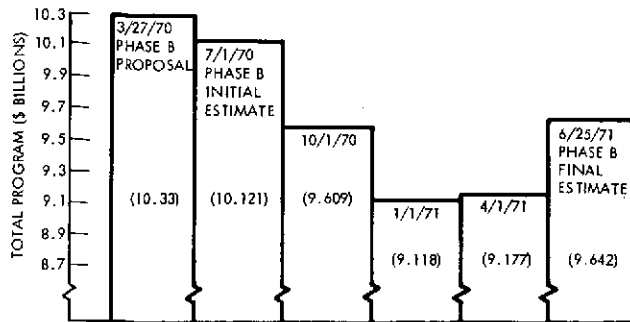
Total shuttle program costs estimated in the Phase B proposal were reduced by \$700 million. These reductions were derived through comprehensive application of cost guidelines in the trade studies, subsystem analyses, and development of cost-effective management and operational plans as the study progressed. The increase in the final estimate was primarily due to increased mission capability requirements instituted midway in the study.

A plan for time-phased funding of the shuttle program for the seventeen-year period beginning with Phase C go-ahead on March 1, 1972, was prepared. During development of the funding profile, consideration was given to constraints imposed by NASA, supporting milestones, cost-schedule trade decisions, and probable Government funding requirements for other programs. The profile is characterized by a small effort in GFY 1972; rapid buildup over the next four years to a peak annual funding of \$2 billion in GFY 1976, and rapid decline over the following four years to an average annual funding of approximately \$100 million for operational service through GFY 1989.

Advanced techniques were employed in developing these cost estimates.

Total Shuttle Program Phase C/D Cost Estimate

Work Breakdown Structure Level 3 Elements	Cost (\$ Millions)**			
	Development	Production	Operations	Total
1.0 Orbiter	3437.5	873.1	322.2	4632.8
2.0 Main engine	*	*	*	*
3.0 Booster	3208.8	440.9	142.7	3792.4
4.0 Flight test	287.8	-0-	-0-	287.8
5.0 Operations	-0-	-0-	703.9	703.9
6.0 Shuttle management and integration	166.3	31.5	27.9	225.7
Total costs	7100.4	1345.5	1196.7	9642.6
Theoretical first unit costs: Orbiter, \$204.3 million Booster, \$285.9 million				
*Government-furnished **Excluded from the cost estimates are main propulsion engine costs, passenger payload module, mission planning and simulation, horizontal test facilities, operational facilities, and contractors' fees.				



*Total Shuttle Program Phase C/D
Cost Estimate History*

Briefly, a Phase C/D work breakdown structure was developed during Phase B to identify similar units of work through the entire seventeen-year Phase C/D contract period to form a framework for cost estimation. A computerized cost model created to fit the work breakdown structure has permitted costing of, not only the specific efforts identified for Phases C and D, but also a large number of related studies and specific changes.

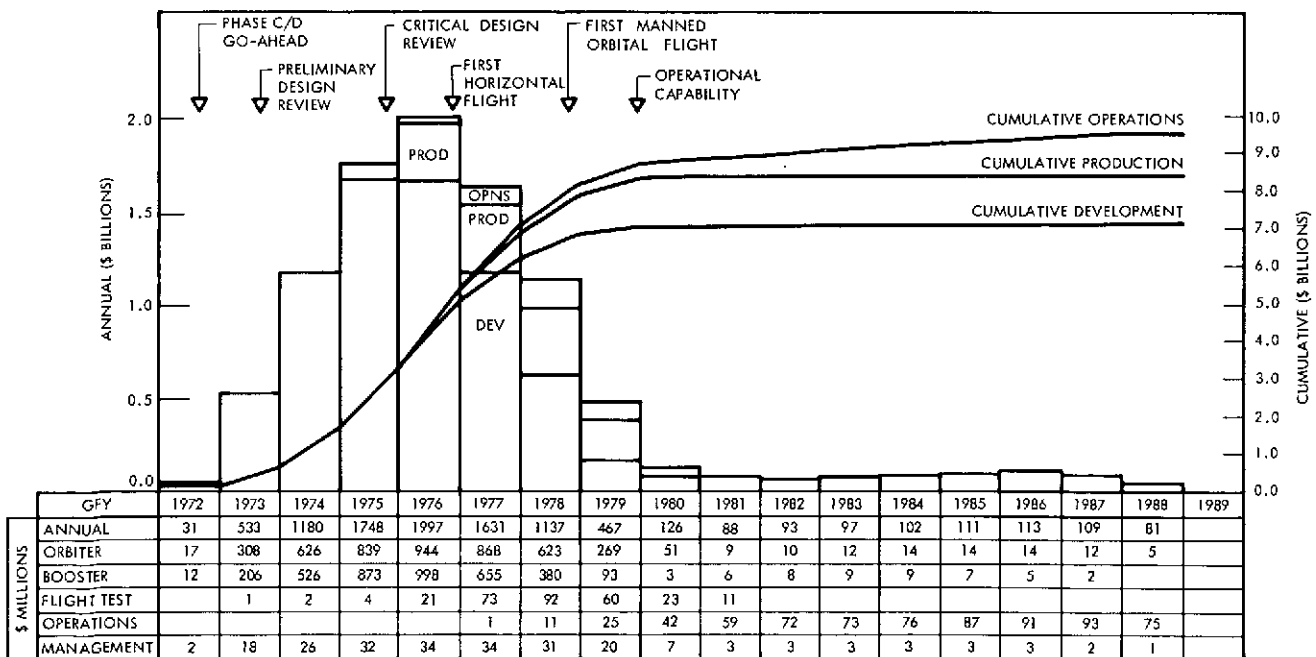
The Phase C/D cost estimates are projected by a parametric pricing technique, in which historical cost data acquired on earlier aircraft and spacecraft programs were employed to project costs of new programs. During the latter part of Phase B, these historical data were replaced where possible with vendor quotes. Only those quotes that were validated and crosschecked by

parametric analysis were included, however. These costing techniques are fully explained in Report SD 71-107, *Program Cost and Schedules*.

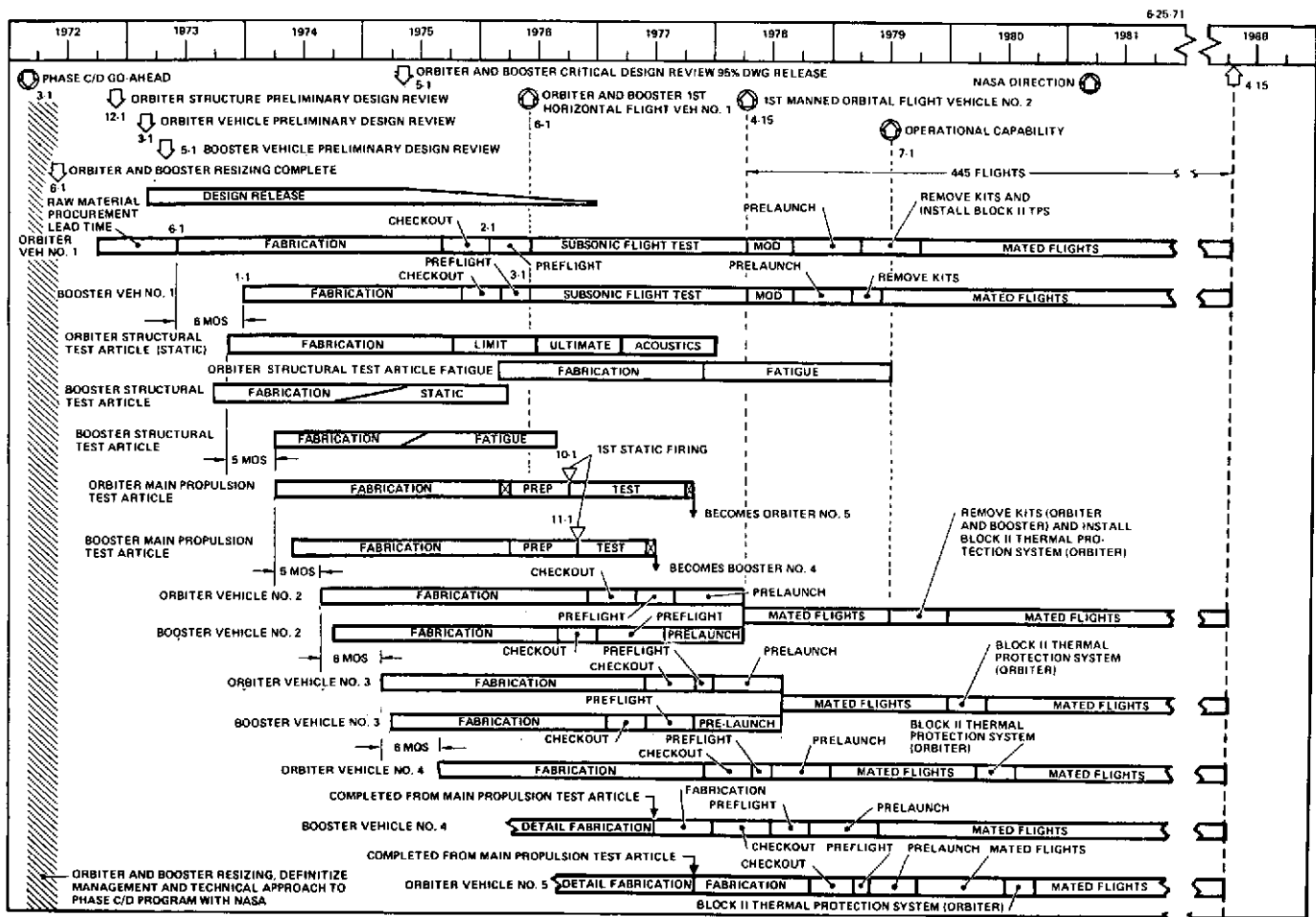
The cost estimates are constrained by the Phase C/D master program schedule, which establishes specific dates for key program events. Derived from the program development logic and time-phased constraint networks, these dates reflect the NASA-established dates for the first horizontal flight (June, 1976), the first manned orbital flight (April, 1978), and operational capability (mid-1979). A date of March 1, 1972, is assumed for Phase C/D go-ahead.

Significant features of this schedule include a three-month period at the beginning of the program reserved for sizing the vehicle identified by the Phase C contract, refining system requirements, definitizing the management and technical approaches, and discussing these approaches and plans with NASA.

Close coordination between the orbiter and booster engineering programs through incremental preliminary design reviews is required to ensure maximum commonality of system and component designs. On completion of these reviews, the orbiter and booster programs may be phased to permit somewhat independent development consistent with overall vehicle design integrity and the common goal of supporting the first manned orbital flight in April, 1978.



Total Shuttle Program Phase C/D Funding Requirement Estimate



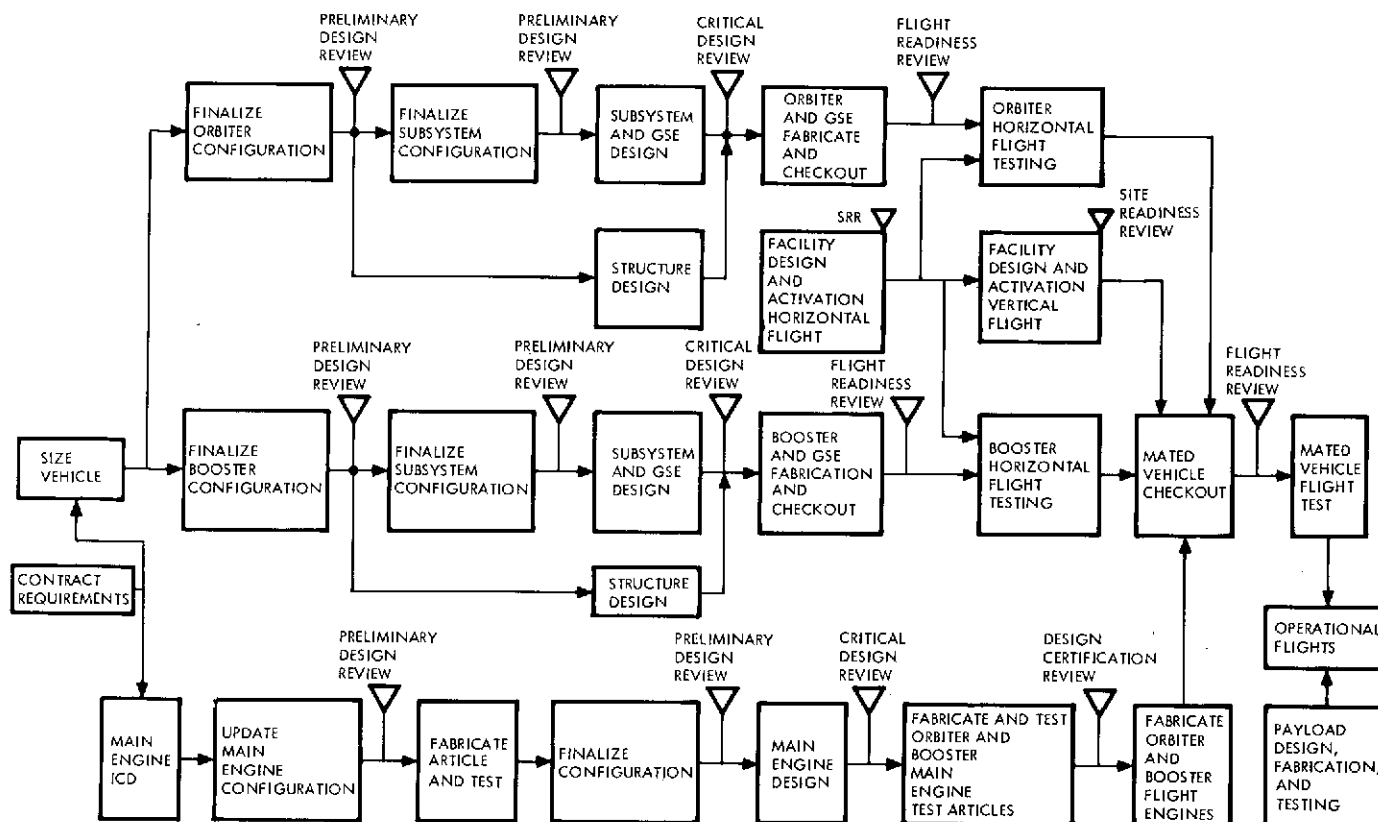
Phase C/D Master Program Summary Schedule

Development test logic was constructed to establish the framework for integrity, compatibility, and safety evaluations. Orderly development of the space shuttle system is assured by organizing the entire program to provide sufficient certification testing. Certification testing comprises development tests, qualification tests, acceptance tests, and flight tests and encompasses, not only flight hardware, but facilities and ground support equipment as well. Development testing involves material, design feasibility, wind tunnel, breadboard, and ground and flight test article activity. Early subsystem integration with software is a key test requirement. Qualification testing is accomplished on production articles whose failure could result in loss of crew life or vehicle. Acceptance testing is conducted on deliverable flight hardware and ground support equipment to demonstrate contractual compliance short of flight testing. Flight testing consists of horizontal flight tests of the individual orbiter and booster vehicles to demonstrate air-breathing engine performance and subsonic atmospheric handling qualities and

vertical flight tests of the mated orbiter and booster, including capability demonstration. Design reviews and audits are conducted at strategic points throughout the program by NASA and the contractors. These points are identified on the development logic diagram.

The cost estimates are also based on timely resolution of major development issues requiring technological advancement. Among these issues are development of the reusable thermal protection system and integration of the data and control management system and the complete propulsion system. Funding is included in the estimates for a number of major test articles, mockups, and models required for development and qualification of the orbiter and booster.

Although the Phase C/D program plans prepared during Phase B were primarily oriented toward providing general requirements, specific implementation approaches were identified to establish a basis for cost estimation. For example, selection of the orbiter and booster final



Shuttle System Development Logic

Orbiter Program Cost Estimate

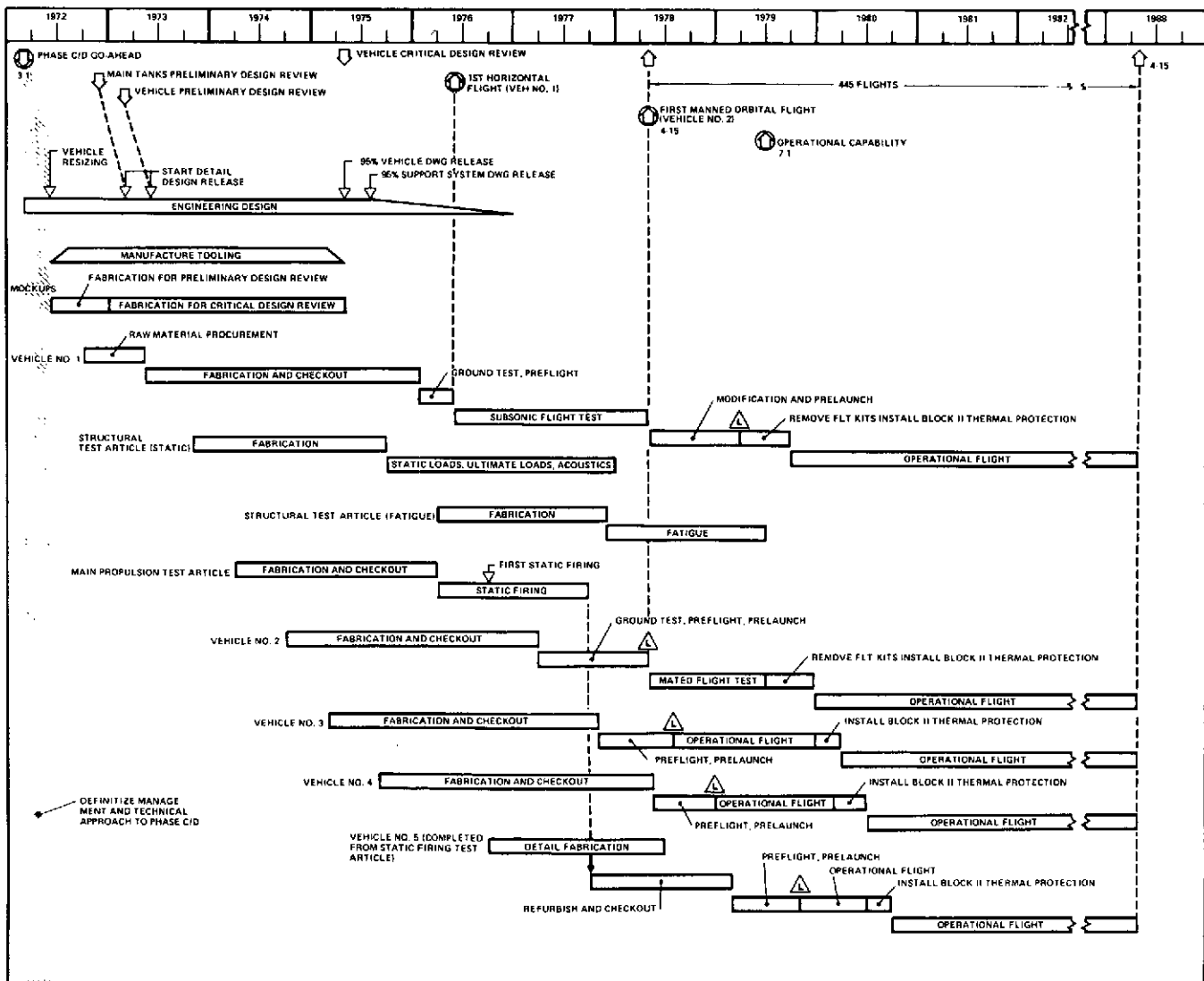
Cost Element	Cost (\$ Millions)			
	Developments	Recurring		Total
		Production	Operations	
1.0 Orbiter – total	3437.5	873.1	322.2	4632.8
1.1 Structural group	1104.2	425.2	87.6	1617.0
1.2 Propulsion group	631.3	164.8	56.7	852.8
1.3 Avionics group	366.8	68.6	72.2	507.6
1.4 Power group	234.4	68.3	25.1	327.8
1.5 ECLS group	187.0	37.8	14.5	239.3
1.6 Installations, assembly, and checkout	99.8	95.5		195.3
1.7 Combined development testing	96.8			96.8
1.8 System engineering	229.6			229.6
1.9 Facilities and activation	2.1			2.1
1.10 System support	413.8		30.9	444.7
1.11 Orbiter management	46.9	12.9	35.2	95.0
1.12 Payload	24.8			24.8
*4.0 Flight test	236.9			236.9
5.0 Operations			703.9	703.9
6.0 Shuttle management and integration	166.3	31.5	27.9	225.7
Total Orbiter Program	3840.7	904.6	1054.0	5799.3
*Does not include 4.2				



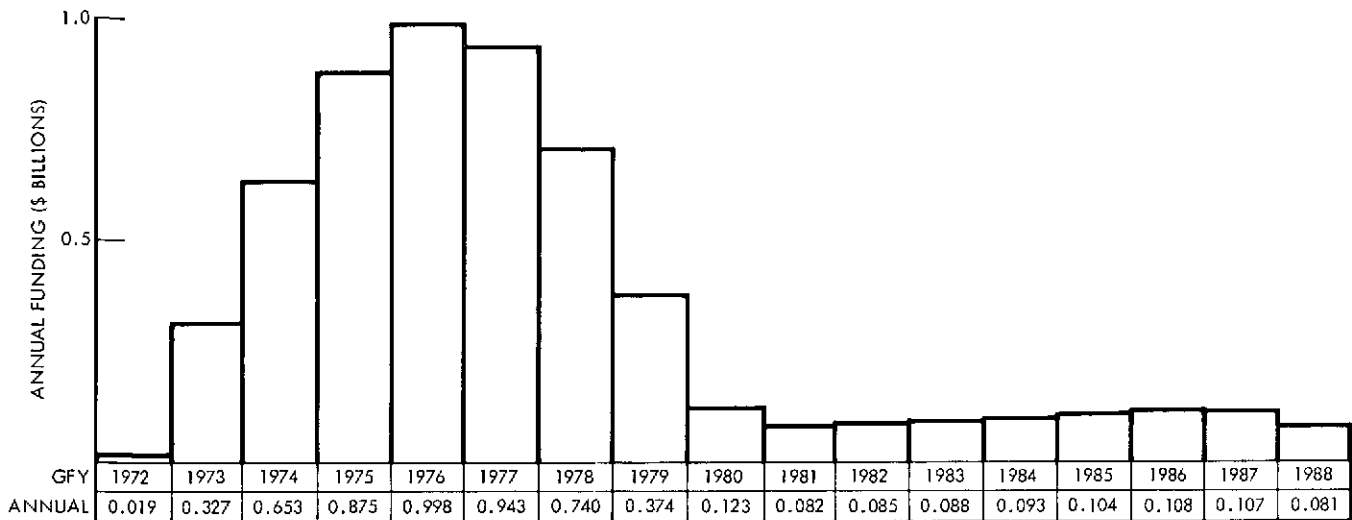
assembly and checkout facilities is a major consideration that affects development of total program costs. Other considerations included flight testing, operations, and management.

The estimated orbiter program cost of \$5.79 billion is based on final assembly of the orbiter vehicle at the North American Rockwell facility at Seal Beach, California, which is immediately adjacent to the existing NASA Saturn S-II Manufacturing Facility. Subassemblies fabricated at sites other than Seal Beach are shipped by truck, rail, or air to the Seal Beach facility. The completed vehicle is transported by barge 65 miles from Seal Beach to Point Mugu, where it undergoes preflight testing. The orbiter is then flown 80 miles to Edwards Air Force Base for the horizontal flight test program. Delivery to the Kennedy Space Center (KSC) for vertical flight tests is by means of ferry flights between airports on a transcontinental

ferry route. Other facility recommendations include main propulsion testing at KSC, auxiliary propulsion testing and air-breathing propulsion testing at White Sands, structural tests at Downey and Huntsville, thermal control testing at Clear Lake, and thermal protection system testing at Wright-Patterson Air Force Base. Power generation, avionics integration, electrical integration, and environmental control and life support system tests are conducted at Downey. Program administration and engineering is headquartered at Seal Beach. These facility selections represent the optimum approach to utilization of existing Government and contractor resources and were based upon a methodical analysis of more than 100 sites across the nation. Resources are identified as skilled aerospace personnel, efficient contractor organizations, in-place machinery and equipment, and buildings and structures.



Orbiter Vehicle Schedule



Orbiter Program Funding Estimate

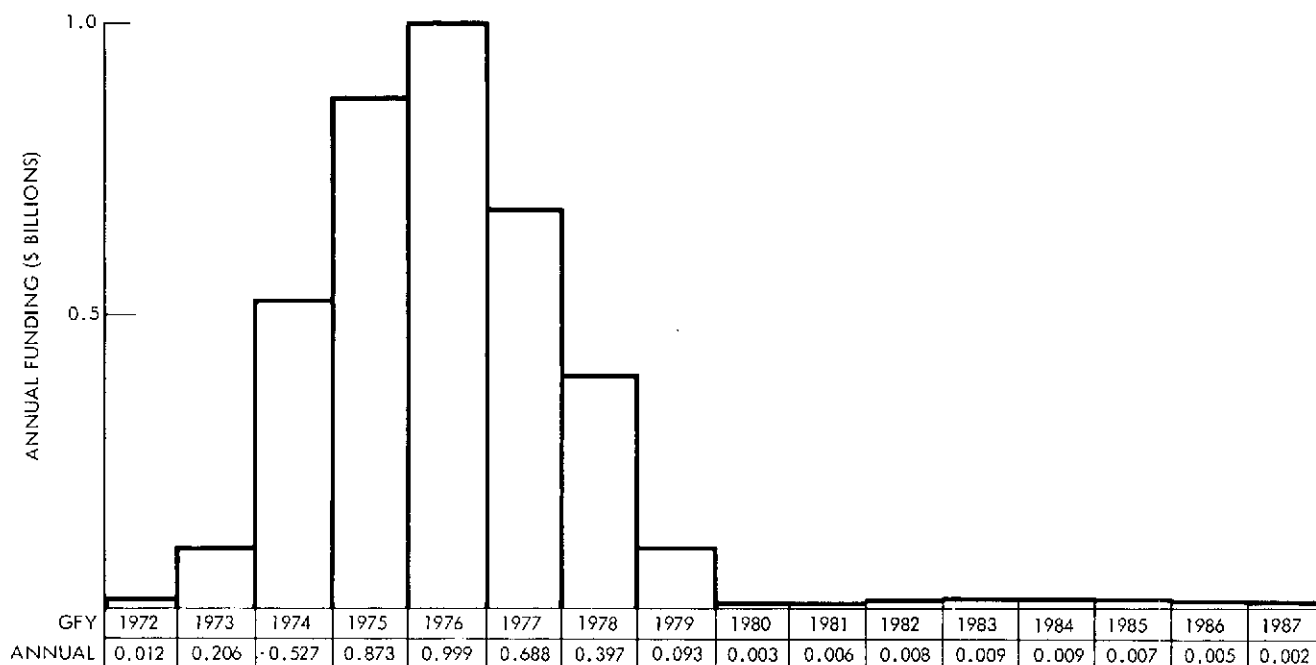
The pacing manufactured item of the orbiter program schedule is the double-conical liquid-hydrogen tank. The five months required for the welding operation using one set of major fabrication and assembly tooling establishes the manufacturing rate for the orbiter. To meet the date for the first horizontal flight test, the first orbiter flight vehicle is fabricated prior to the structural test article and main propulsion test article. The second orbiter flight vehicle is phased in the manufacturing sequence after the main propulsion test article to support the first manned orbital flight. Following static firing tests, the main propulsion test article is modified and delivered as

the fifth flight vehicle. This plan provides adequate time for structural limit load tests before the first horizontal flight. Ultimate load, acoustic, and the necessary fatigue testing, as well as the main propulsion static firing program, are accomplished before the first manned orbital flight. The orbiter program cost estimate is based on this schedule and the program plans. The associated funding profile is similar to that of the total space shuttle program with a peak funding requirement of approximately \$1.0 billion in GFY 1976.

The booster program cost estimate of \$3.84 billion assumes final assembly of the booster vehicle at the NASA Michoud Facility,

Booster Program Cost Estimate

Cost Element	Cost (\$ Millions)			
	Development	Recurring		Total
		Production	Operations	
3.0 Booster	3208.8	440.9	142.7	3792.4
3.1 Structural group	1294.1	227.2	13.7	1535.0
3.2 Propulsion group	551.5	87.5	30.6	669.6
3.3 Avionics group	363.7	45.7	58.7	468.1
3.4 Power group	276.2	38.3	25.9	340.4
3.5 ECLS group	31.5	1.7	1.1	34.3
3.6 Installation, assembly, and checkout	58.5	40.5		99.0
3.7 Combined subsystem development testing	150.2			150.2
3.8 System engineering and integration	162.0			162.0
3.9 Facilities	11.8			11.8
3.10 System support equipment and services	272.5		12.7	285.2
3.11 Booster management	36.9			36.9
4.2 Booster vehicle test	50.9			50.9
Total Booster Program	3259.7			3843.3



Booster Program Funding Estimate

Louisiana, where much of the Saturn S-IC stage tooling is located. Following booster checkout at Michoud, the vertical stabilizer and wing tips are removed, and the booster is transported by barge to KSC for final assembly, checkout, and horizontal flight testing. Other facility recommendations include structure and separation tests at Huntsville, main propulsion and full-scale vibration tests at KSC, avionics and power generation tests at San Diego, and crew escape sled tests at Holloman AFB. These facility selections also represent the optimum approach to utilization of existing national skilled manpower, equipment, and facilities.

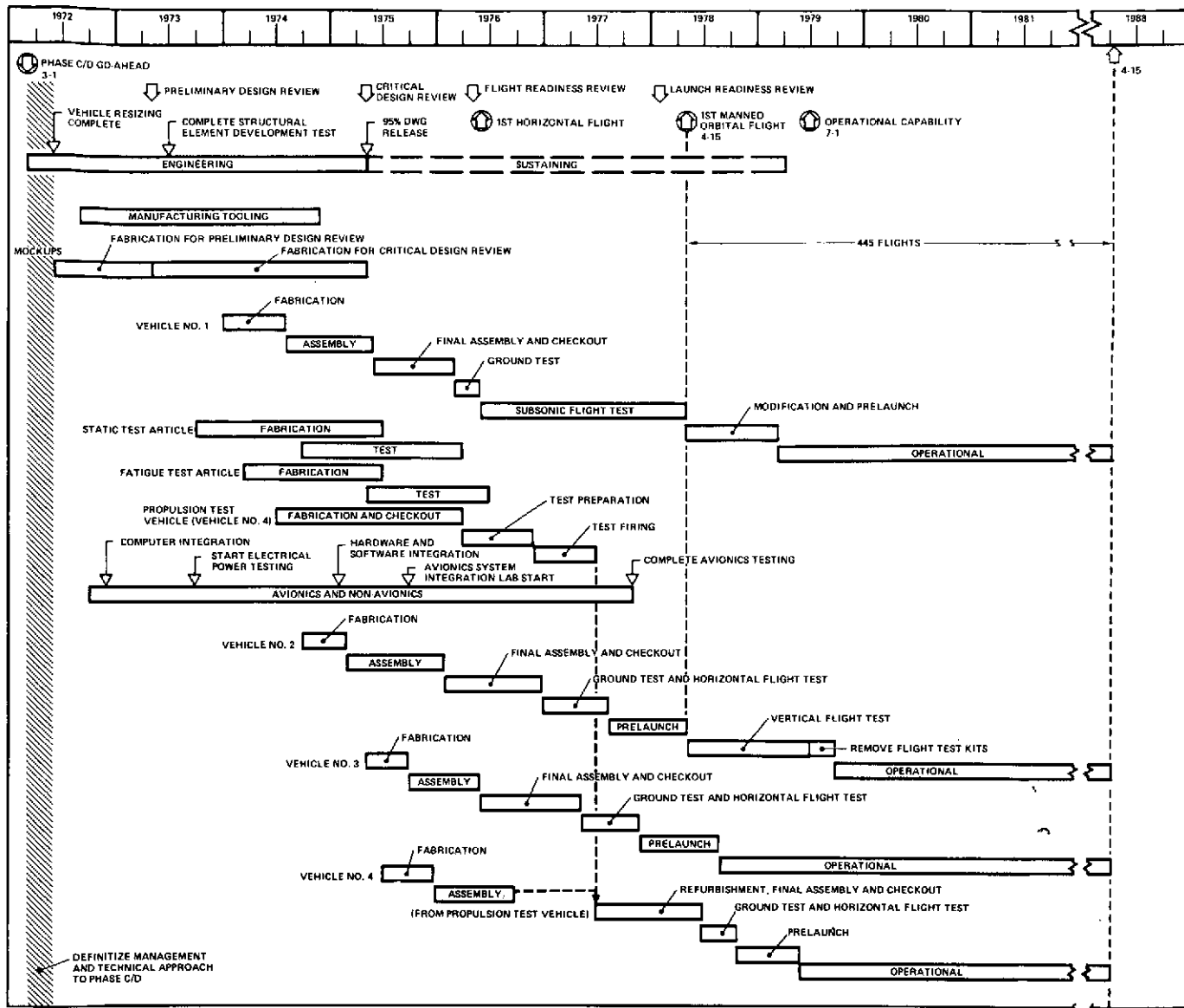
The schedule estimate for the booster program indicates a shorter manufacturing span than that of the orbiter. The manufacturing rate between the major test articles and the flight vehicles is based on minimizing duplication of major structural assembly tooling. The first booster flight vehicle supports the horizontal flight test program. Scheduling of the booster structural test articles allows a minimum of eight months of structural testing to limit loads before first horizontal flight. The booster main propulsion test article allows a minimum of four months for test stand integration and nonfiring tests and a minimum of seven months for static firing tests; then it is modified to flight configuration and delivered to the operational fleet as the fourth flight vehicle. The second flight vehicle is scheduled to support

the first manned orbital flight. The booster program cost estimate is based on this schedule and the program plans.

The space shuttle flight test cost estimate of \$288 million comprises orbiter and booster horizontal flight testing and the related mission planning, maintenance, and support activities. Excluded from the estimate are horizontal flight test facility costs.

The operations cost estimate of \$704 million considers tasks essential for effective routine missions of the space shuttle. These tasks include propellant and gas supplies, spare parts, training, ferry operations, vehicle and equipment maintenance, and facilities operations. Excluded are mission planning and simulation, operational facilities, and payload modules.

The management cost estimate of \$226 million is based on implementation of management criteria described in the program management plan for the orbiter, booster, flight test, and operations portions of the space shuttle program. Cost effectiveness was a primary consideration in formulating these criteria and the proposed implementation approach. Each requirement has been considered in the light of current and recent experience to assure that a real management need exists and that the requirement is economically achievable. Resulting cost and schedule planning and control system requirements represent the best features of the Apollo and Atlas programs and the



Booster Vehicle Schedule

concepts contained in NASA and DOD planning and control documents. The recommended approach includes a reduction in long-range planning at a detail level; detail planning below the program level is most cost-effective if accomplished on an annual basis. Advanced cost and schedule problem warning is provided by a system that compares the planned value of work scheduled with the actual cost of that work. This advanced management system was demonstrated during Phase B. Cost, schedule, and technical data redundancy is minimized by fulfilling customer docu-

mentation requirements using, whenever possible, contractor internal documentation without form or format changes. Excluded from this management cost estimate is the task of total space shuttle program management.

Results of the planning, cost estimating, and scheduling efforts have been successful in defining a low-cost space shuttle program. Through these efforts, a higher level of confidence has been established in the costs and schedules developed for this program than for any previous large program.



PHASE B STUDY MAJOR DOCUMENTATION

	<u>DRL-M010</u> <u>Line Item No.</u>	<u>NASA</u> <u>Control No.</u>	<u>Contractor</u> <u>Control No.</u>
Phase B Control			
Study Plan	1	MSC-03300	SD 70-1
Test Plan	2	MSC-03301	SD 70-7
Structural Test Program Plan	7	MSC-03322	SD 70-409
Cost/Design Performance Management Plan		MSC-03320	SD 70-402
Design Definition			
System Definition Handbook	10	MSC-03306	SD 70-401
Interface Control Documentation	9	MSC-03305	SD 71-127
Orbiter Vehicle Prime Item Specification	21	MSC-03315	CP613M0002
Booster Vehicle Prime Item Specification	21	MSC-03315	76Z0500
System Specification Space Shuttle System	22	MSC-03316	SS613M0001
Ground Systems Specification	22	MSC-03316	76Z0501
Form 1 Drawings (ICD)	20	None	
Orbiter to Launch Facility			9992-1351
Orbiter to Maintenance and Refurb GSE			9992-1352
Orbiter to Payload			9992-1353
Orbiter to Space Station			9992-1354
Booster to Orbiter			76Z0200
Booster/Orbiter to Launcher			76Z0201
Form 2 Drawings (Design Evaluation)	24	MSC-03326	
Orbiter			SD 71-128-1
Booster			SD 71-128-2
Aerothermal Wind Tunnel Data	5	None	*
Mass Properties Monthly Status Report	4	MSC-03302	SD 70-403
Mass Properties Detail Report	23	MSC-03317	SD 71-144
Propulsion Trade Documentation	6	MSC-03303	
Thrust Level			SD 70-600-25
Expansion Ratio and Emergency Power Level			SD 70-600-28
Throttle Requirements			SD 71-601-14
Thrust Vector Control			SD 70-601-8
Fixed and Gimbale Boost Pumps			SD 70-601-2
Nozzle Extension Operating Requirements			SD 70-601-1
Vehicle Thrust Profile			SD 71-601-15
ACPS Vs Main Propulsion/OMS, Requirement, Duty Cycle			SD 71-601-16
Engine Controller			SD 71-601-7
Engine Electrical Power			SD 71-601-5
Base Heating			SD 71-601-9
Separation Mode			GD 76-546-10-002
Engine Structural Loads			SD 70-601-4
PU Requirements			Letter 71MA173 (1-6-71)
Abort Requirements			SD 70-600-10
Engine Prestart Conditioning			SD 70-601-11
Propellant Tank Pressurization			SD 70-601-10
Air-breathing Engine Requirements			SD 70-601-12
Auxiliary Power Unit			SD 71-601-17
Pogo Analysis			SD 71-601-18
Vehicle Feedline Configuration			SD 70-601-13
Expendable Second Stage Study Final Report		MSC-03321	SD 71-140
DOD Impact Study Final Report (Secret)		None	SD 71-142
External Hydrogen Tank Study Final Report		MSC-03327	SD 71-141
Supporting Research and Technology			
Technology Requirements Report (Quarterly)	8	MSC-03304	SD 70-8
Independent Research and Development Activities Report			Quarterly Letters
Phase C/D Plans			
Program Management	13	MSC-03308	SD 71-101
Engineering & Development	14	MSC-03309	SD 71-102
Operations	15	MSC-03310	SD 71-103
Facilities Utilization and Manufacturing	16	MSC-03311	SD 71-104
Preliminary Test	17	MSC-03312	SD 71-105
Logistics and Maintenance	18	MSC-03313	SD 71-106
Program Cost and Schedules	19	MSC-03314	SD 71-107
Phase C/D Schedule Baseline	26	MSC-03325	SD 71-124
Phase B Final Report			
Volume I. Executive Summary	12	MSC-03307	SD 71-114-1
Volume II. Technical Summary			SD 71-114-2
Volume III. Plans Summary			SD 71-114-3

*Inputs to SADSAC reports issued by Chrysler Corp. Space Division